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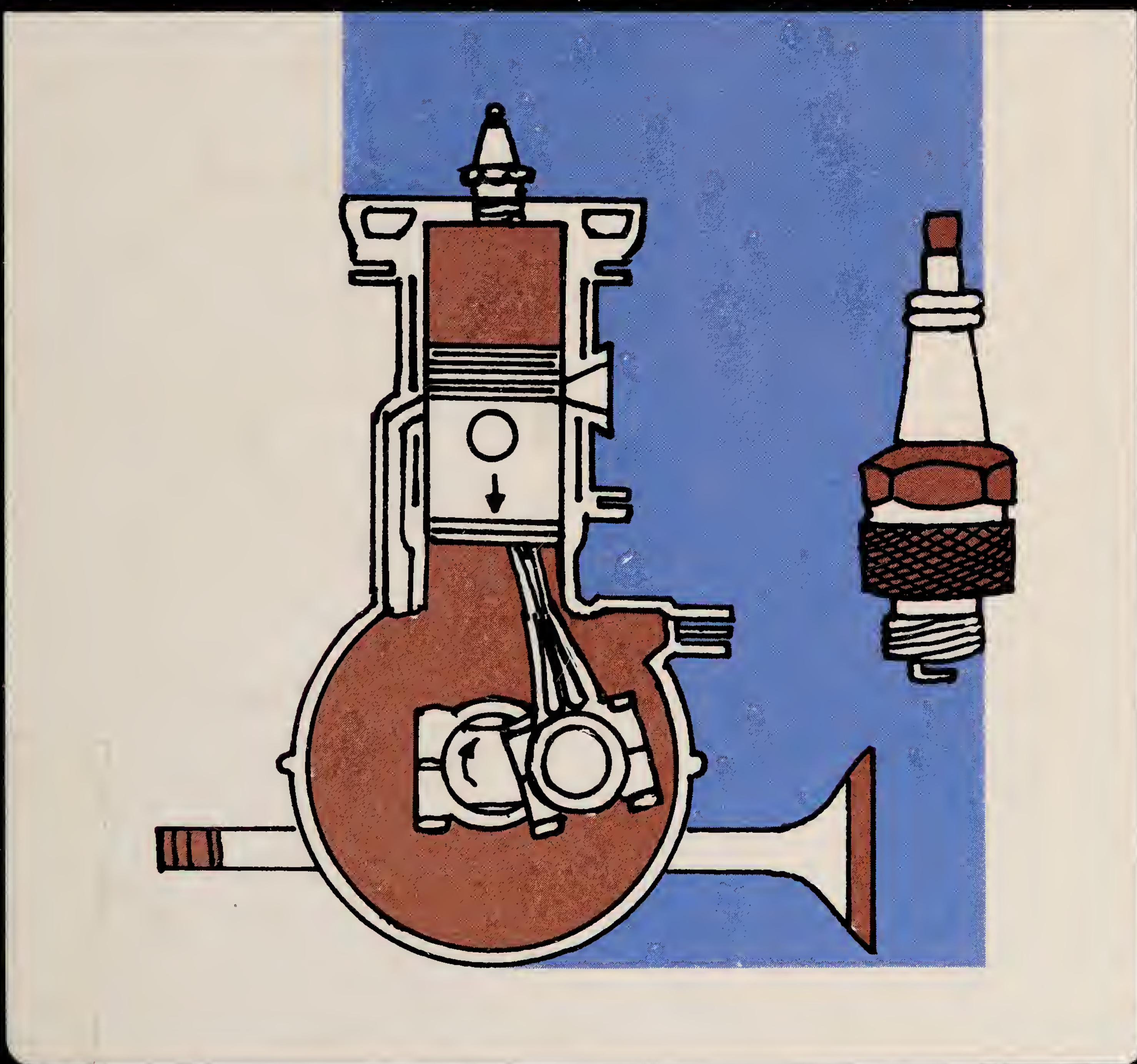
# GAS ENGINE MANUAL



By Edwin P. Anderson
Revised by Charles G. Facklam

# Gas Engine Manual

by Edwin P. Anderson
revised by Charles G. Facklam

Rex Miller, Consulting Editor





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# Contents

## CHAPTER 7



## CHAPTER 8



## CHAPTER 9



## CHAPTER 10



## CHAPTER 11



## CHAPTER 12

## CHAPTER 13



## CHAPTER 14



## CHAPTER 15



## CHAPTER 16



## CHAPTER 17



## CHAPTER 18

## CHAPTER 19



## CHAPTER 20



## CHAPTER 21



## CHAPTER 22



## CHAPTER 23



## CHAPTER 24



## CHAPTER 25

## CHAPTER 26



## CHAPTER 27



## CHAPTER 28



## CHAPTER 29

# Preface

The purpose of this book is to serve as a helpful guide to mechanics and students whose work deals with the operation, maintenance and repair of modern gas engines of various types and sizes.

Although the gas engine principle is not new, it is only in recent years that its service as a prime mover has multiplied to include almost every field of human activity, from that of motor transportation to the running of various appliances around the home. Other uses include outboard motors and marine and aircraft engines.

The book explains the operating principles of various types of gas engines, then goes on to illustrate the function of the various engine parts and necessary accessories, such as carburetors, fuel ignition methods, and cooling and lubricating systems. It also deals with troubleshooting and modern service operations, including engine tune-up and emission control procedures. The various ignition system items that affect engine performance are fully listed and illustrated.

CHAPTER 1

# Gas Engine Fundamentals

The gas engine is an internal combustion machine which derives its power from the heat generated when a compressed air-fuel mixture is ignited within its cylinders.

The fuel most commonly used in internal combustion engines as the source of power is gasoline. Other fuels include benzol, alcohol, fuel oil, butane, propane and natural gas. Any of these fuels may be used efficiently in the cylinder of an internal combustion engine.

## OPERATING PRINCIPLES

The process by means of which the engine produces power is based on a fundamental law of physics which states that gas will expand upon application of heat. If the gas is confined, however, with no outlet for expansion, then the pressure of the gas will be increased

when heat is applied as the result of igniting the compressed gas in an internal combustion engine.

In an engine, this pressure acts against the head of a piston, causing it to move away from the combustion chamber. The piston, being connected to the crankshaft by the connecting rod, converts this linear or straight-line force into rotary motion and supplies power to a crankshaft and associated flywheel.

The air-fuel mixture is admitted to the engine intermittently, and the amount supplied at each admission is known as the *charge*. The combustion of each charge takes place under pressure attained by *compression* as a result of the upward movement of the piston after the charge is admitted and all valves are closed.

The effect produced by igniting the mixture after compression is commonly mistermed an *explosion*, which is simply a quick burning or rapid combustion of the mixture. This sudden combustion causes a high degree of heat within the combustion chamber, resulting in considerable initial pressure that decreases in intensity while the piston advances down the power stroke. The products of combustion are finally exhausted from the cylinder.

The term *cycle* as applied to an engine is defined as a series of events which are repeated in regular order and which constitute the principle of operation. Expressed briefly, the cycle of a gas engine embraces:

1. The admission of a fresh charge of gas and air into the cylinder.
2. Compression and ignition of the combustible mixture.
3. Expansion of the ignited charge and absorption of its energy.
4. Expulsion of the burned gases.

These four events are called, respectively: Intake, Compression, Power and Exhaust.

In the operation of a gas engine the number of strokes required to complete the cycle varies with the type of engine. Thus, in a two-stroke-cycle engine, the cycle of events is completed in two strokes of the piston. On such engines, each cylinder delivers a power stroke at every revolution of the crankshaft.

In the four-stroke-cycle engine, on the other hand, the cycle is extended through four strokes, two downward and two upward.

Thus, there is only one power stroke for every two revolutions of the crankshaft.

## Two-Stroke-Cycle Engines

Two-stroke-cycle engines may have two or more ports and also utilize poppet, reed, rotary disk or drum-type valves. In two-stroke-cycle engines, the crankcase is used as a receiver for the air-fuel mixture before it enters the cylinders through passages connected with port openings in the cylinder walls. The ports are covered and uncovered by the action of the piston as it moves up and down within the cylinder. See Fig. 1-1.

The air-fuel mixture enters the crankcase through the fuel admission port opening, equipped with a vacuum or mechanically controlled valve. The air-fuel ratio is controlled by carburetion action.

It is in this manner that the intake port supplies the combustible

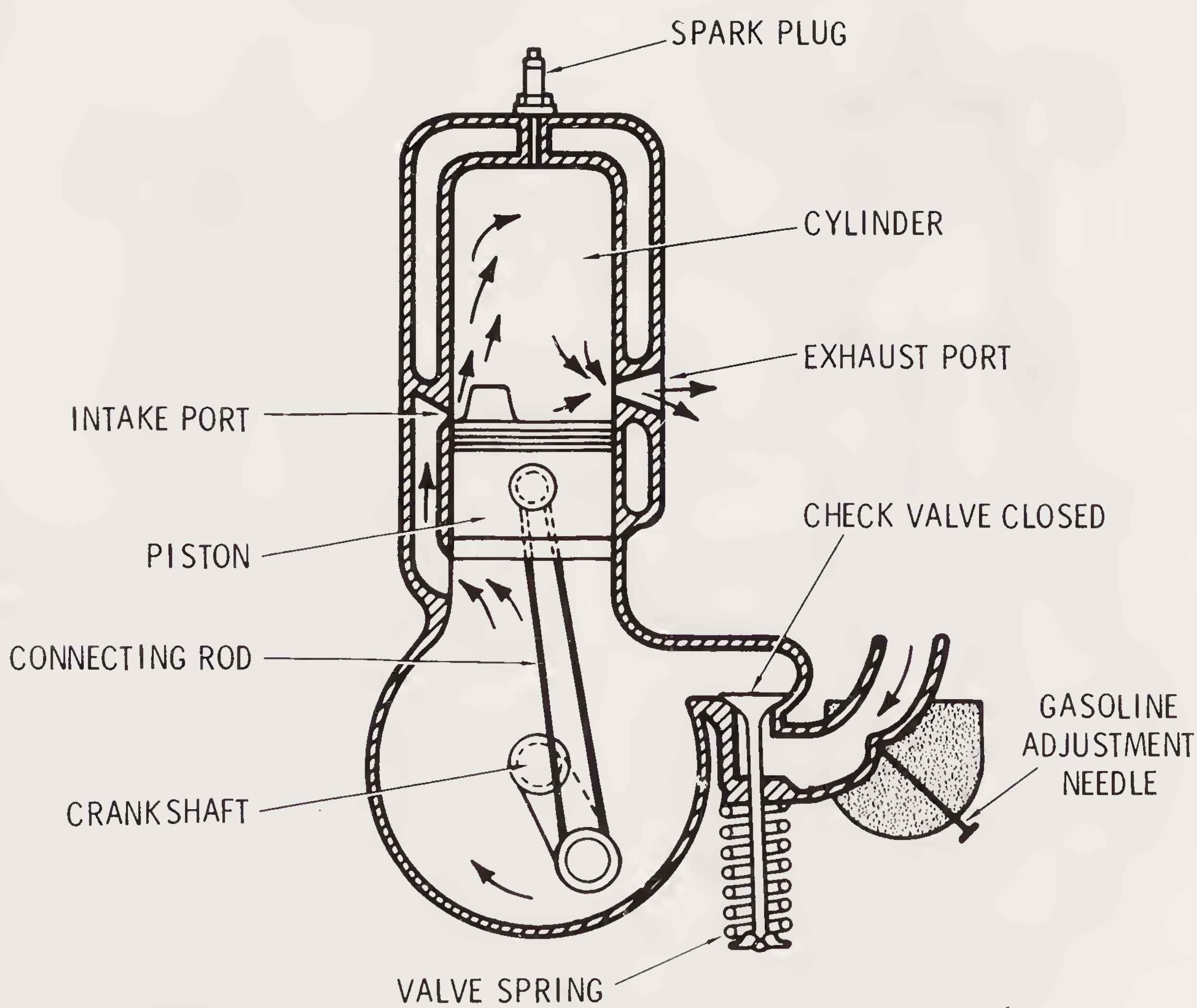



**Fig. 1-1. The principal parts of a two-stroke-cycle gas engine.**

mixture to the crankcase, and the exhaust port discharges the burnt gases into the exhaust pipe and muffler.

The basic principle of a complete operating cycle from the moment the mixture is ignited by the spark plug will be as follows: (With reference to Fig. 1-2, it will be noted that at this point the piston is almost at the end of its upward stroke and the crankshaft throw is about to pass over center.)

A charge of gasoline and air has been pulled into the crankcase by the vacuum created during the upward movement of the piston. This mixture remains trapped in the crankcase because both the intake and exhaust ports are covered by the piston skirt. The fresh charge of gasoline and air in the cylinder has been compressed by the upward movement of the piston. The ignition timing mechanism causes the spark plug to fire at about this point.

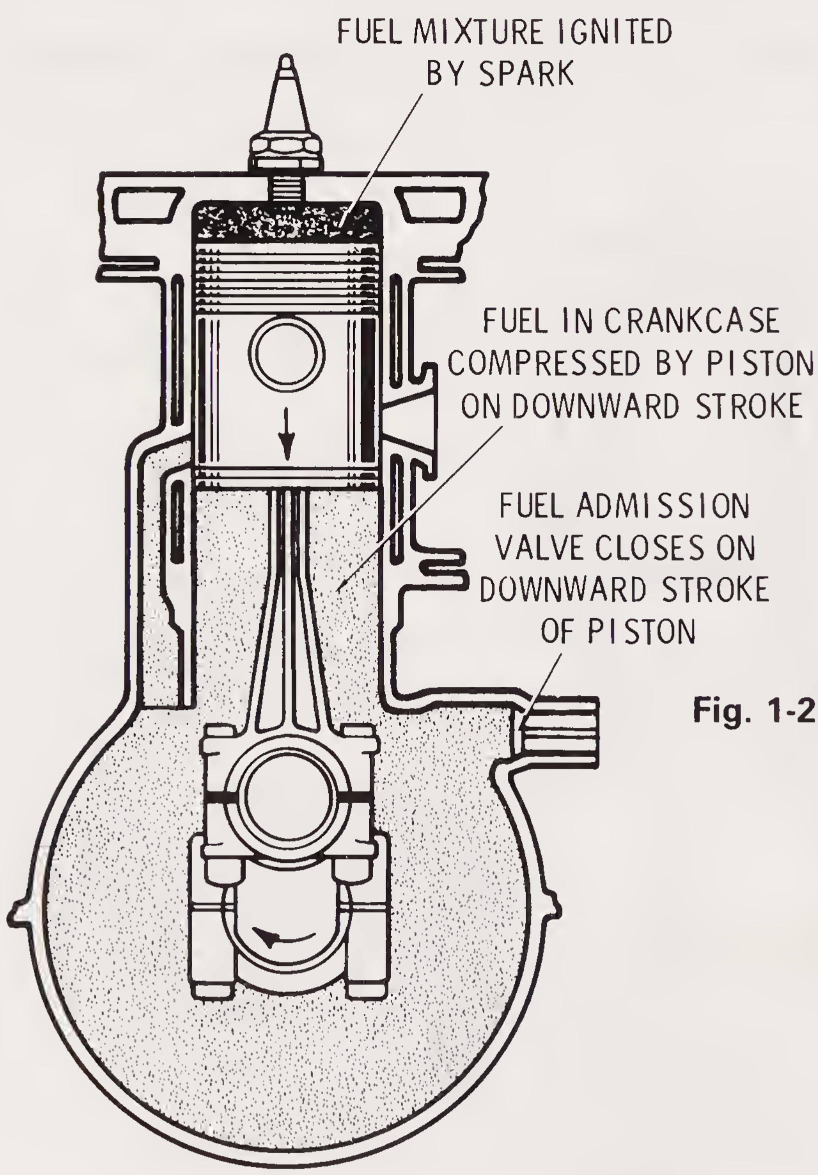



**Fig. 1-2. The view of a two-stroke engine with piston in the upward position.**

In Fig. 1-3, the piston is partway down on the power stroke. The heated gases expand and force the piston downward, which causes the crankshaft throw to deliver power to pull the load. As the piston travels down the valve the reeds are forced onto their seats, preventing the mixture of air and gasoline trapped in the crankcase from escaping back into the carburetor. This mixture is slightly compressed by the downward travel of the piston.

In Fig. 1-4, the piston has reached the end of its downward movement, or *power stroke.* The compressed crankcase mixture is now permitted to enter the intake port. As this fresh material speeds into the cylinder chamber it assists to expel the combusted materials through the exhaust port.

On the upward stroke of the piston, Fig. 1-5, a fresh charge of gasoline, oil and air are taken into the crankcase (fuel admission valve open). As the piston on its upward movement reaches the top

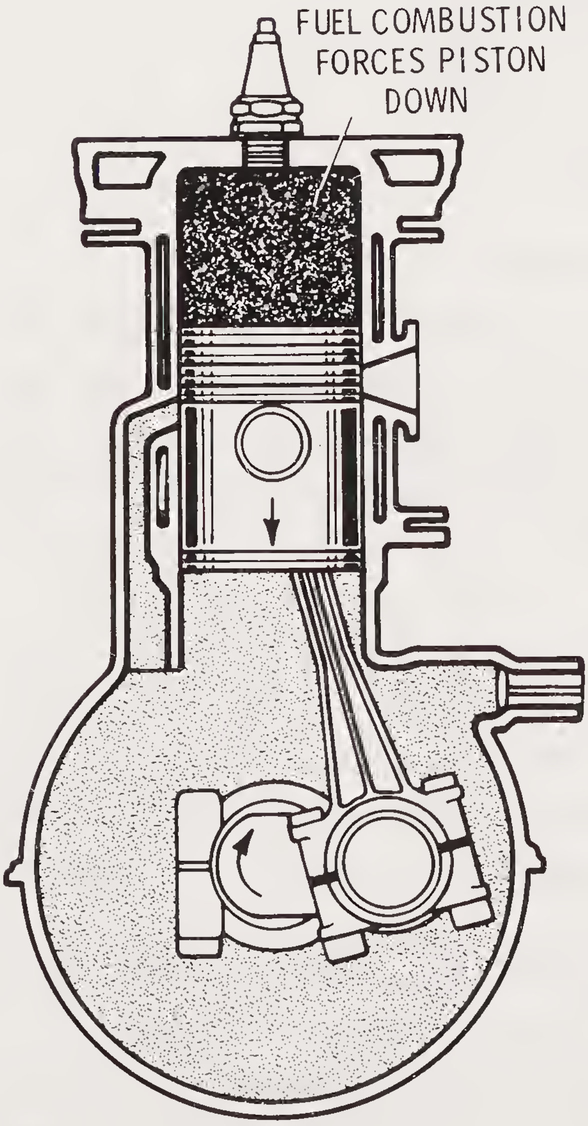



**Fig. 1-3. The view of a two-stroke engine with the piston on its downward movement.**

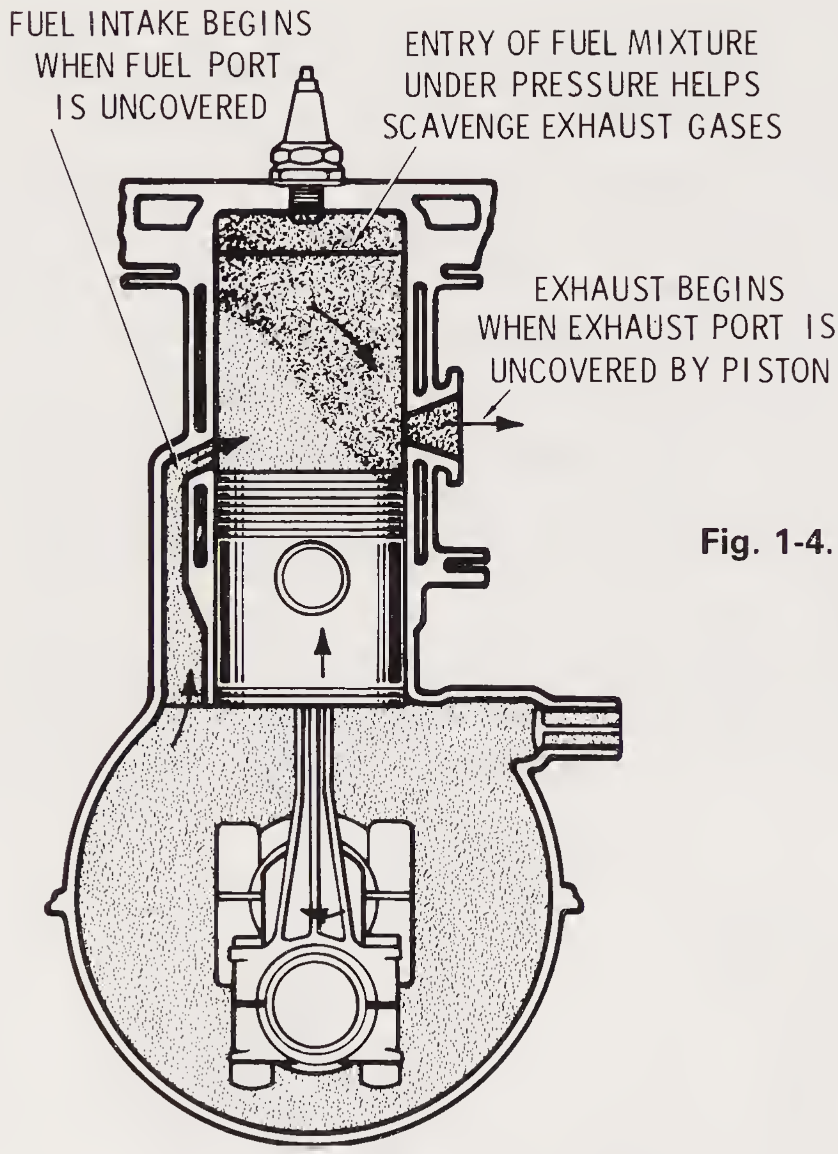



**Fig. 1-4. The view of a two-stroke engine with the piston in the downward position.**

of the cylinder, the spark plug will again ignite the fuel charge. The downward movement of the piston results in a constant turning of the crankshaft and consequent supply of power to the load. The foregoing cycle must be repeated several times a second to maintain operation and produce usable power.

## Four-Stroke-Cycle Engine

Gas engines that need four strokes of the piston, two up and two down, to complete the cycle are known as *four-stroke-cycle* engines. Thus, it requires two complete revolutions of the crankshaft to complete the cycle.

Engines of this type operate in the same manner as that of the well-known automobile engine. As noted in Figs. 1-6 through 1-9, which illustrate the four strokes forming the complete cycle, the inlet valve controls the fuel-air admission into the combustion cham-

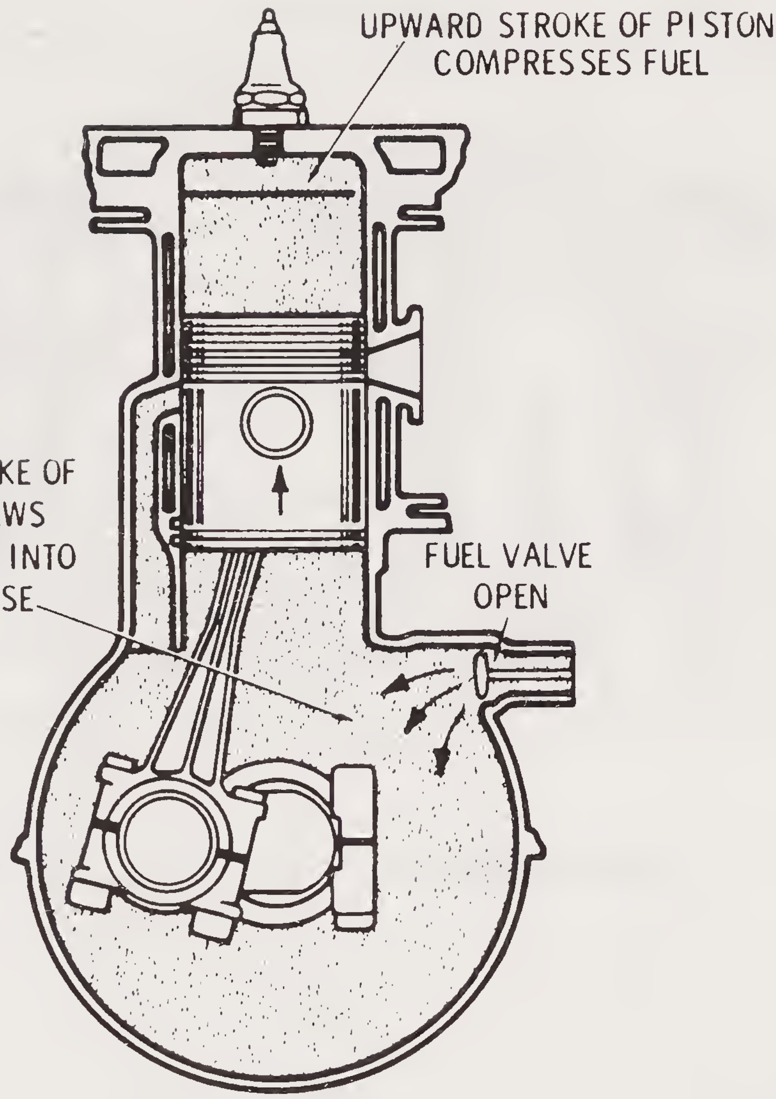



**Fig. 1-5. The view of a two-stroke engine with the piston on its upward movement.**

ber, and the exhaust valve, as the name implies, controls the escape of the burnt gases from the cylinder. These valves are controlled by an operating mechanism from the engine shaft. The other parts of the engine are substantially the same as on the two-stroke engine.

The fundamental difference between the operations of the four-stroke-cycle and the two-stroke-cycle engine is that in a four-stroke-cycle engine all operations take place separately within the cylinder above the piston, whereas in a two-stroke-cycle engine the operations take place simultaneously on both sides of the piston.

The four strokes comprising the working cycle are termed as: (1) Intake; (2) Compression; (3) Power; and (4) Exhaust. The foregoing events are produced substantially as follows:

The *intake stroke* (Fig. 1-6) is the first step in the cycle and commences with the piston in its topmost position, known as *top*

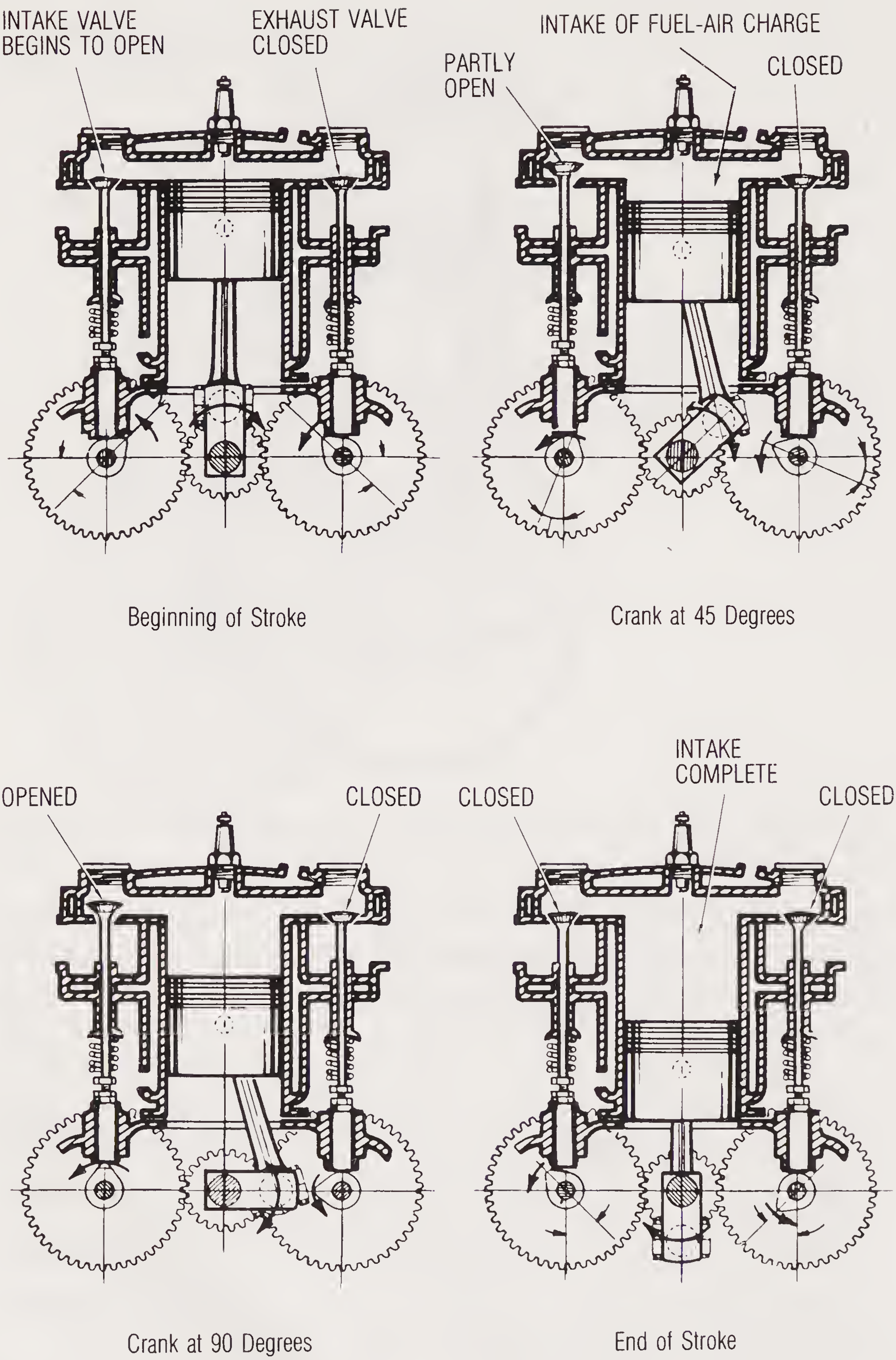



**Fig. 1-6. The intake stroke in a four-stroke engine.**

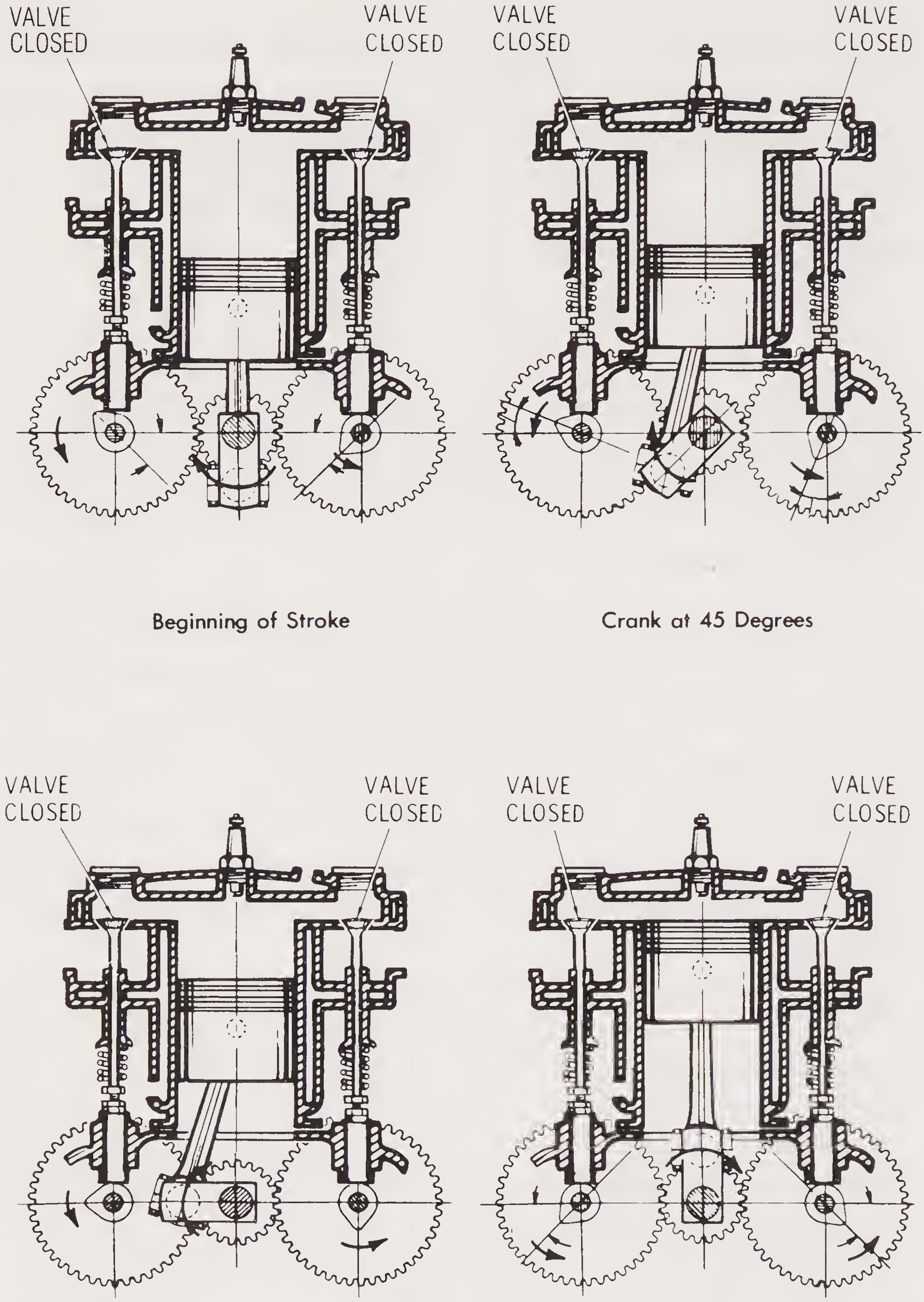
*dead center.* As the piston moves downward a vacuum is created in the cylinder above the piston, permitting the air-fuel mixture to be drawn into the cylinder from the carburetor through the open intake valve. When the piston reaches the bottom of its stroke, the intake valve closes, sealing the fuel-air mixture in the cylinder. The piston has now reached the bottom dead center. Note position of cams operating the valves.

The *compression stroke* is the next step in the cycle. As noted in Fig. 1-7, at the beginning of the stroke the piston is at the bottom dead center position and both valves are closed and remain closed during the entire stroke. As the piston moves upward the air-fuel charge is compressed to as little as one-fifteenth of its original volume in the combustion chamber above the piston. The crankshaft at this point has made one complete revolution. This completes the compression stroke.

The third step in the cycle is the *power stroke*, the only one that contributes to the engine output. As noted in Fig. 1-8, the piston is at its top dead center position. The compressed air-fuel mixture at this time is ignited by an electric spark, generated at the spark plug gap. The heat of combustion causes the burning gases to expand, forcing the piston to move downward, and produces mechanical energy to turn the crankshaft. Both the intake and exhaust valves remain closed during the power stroke. The crankshaft at this point of the cycle has made one and one-half complete revolution.

The final step in the cycle is termed the *exhaust stroke*, since its function is to exhaust the burned gases in preparation for the commencement of another cycle. During the upward movement of the piston, from the bottom to top dead center, Fig. 1-9, the exhaust valve is open to expel the burnt gases from all parts of the cylinder. When the piston again reaches its maximum upward position, the exhaust valve closes and the cylinder is then ready for another cycle.

It will be noted that during the step-by-step description of the four-stroke cycle, the crankshaft made two complete revolutions and the piston made four strokes. The same sequence of *intake, compression, power* and *exhaust* must always occur in the same order and must be repeated several times a second to operate the engine and produce useful power.




Beginning of Stroke

Crank at 45 Degrees

Crank at 90 Degrees

End of Stroke

**Fig. 1-7. The compression stroke in a four-stroke engine.**

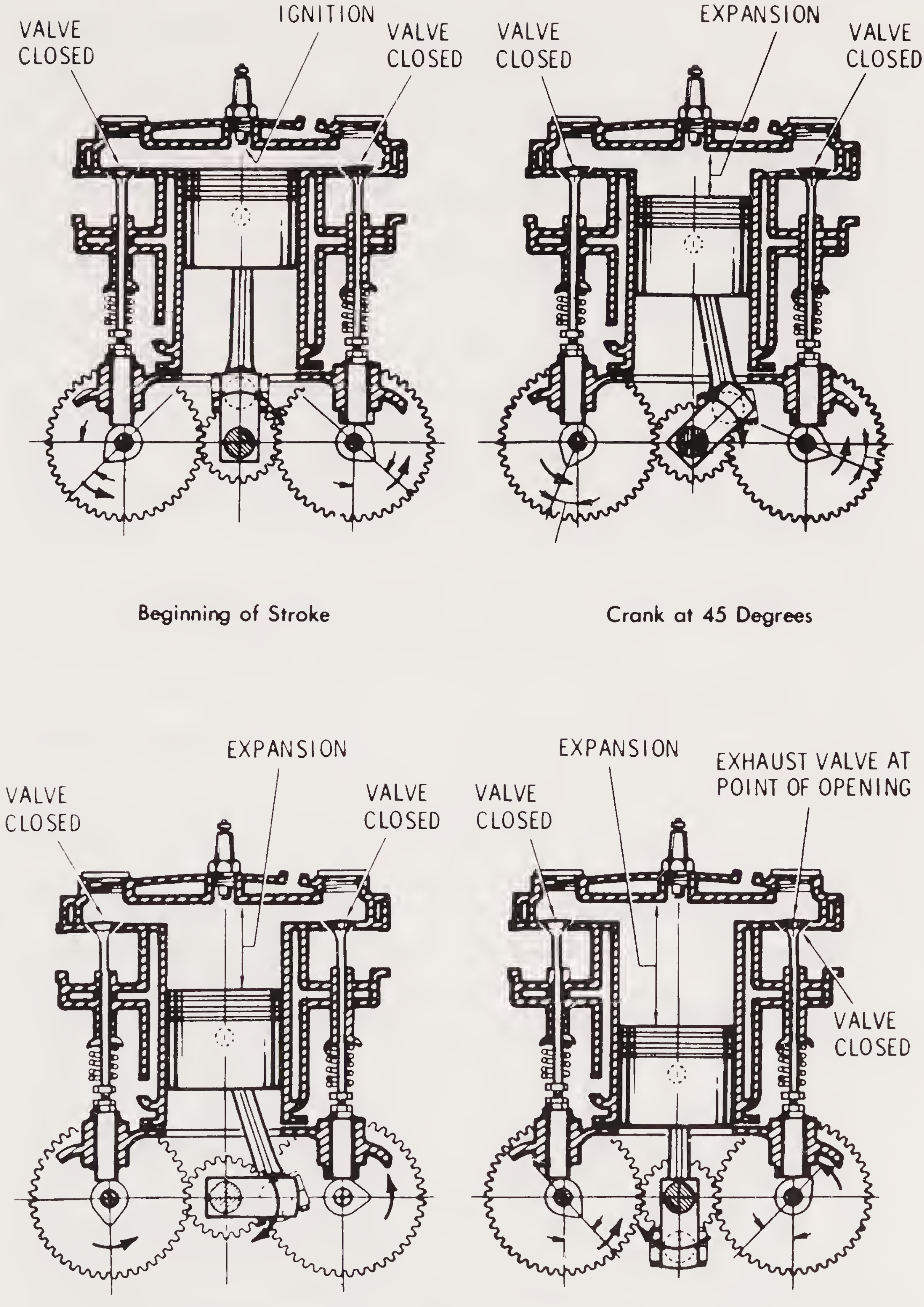
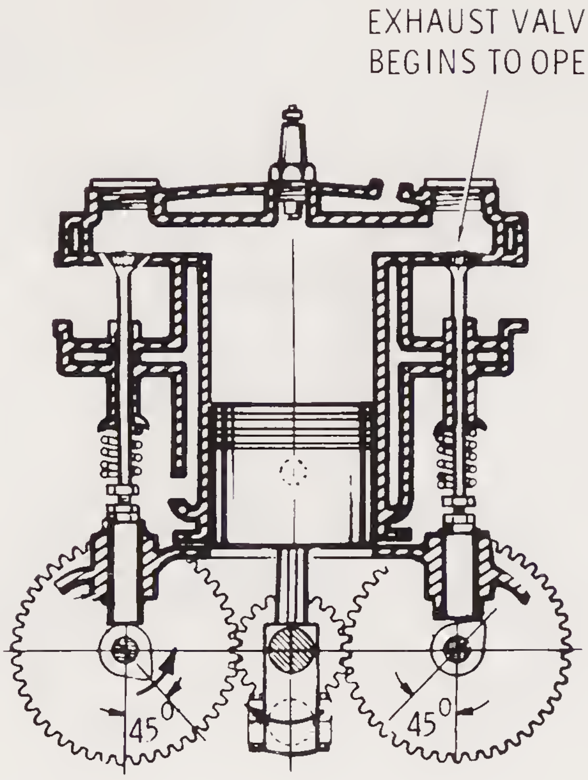
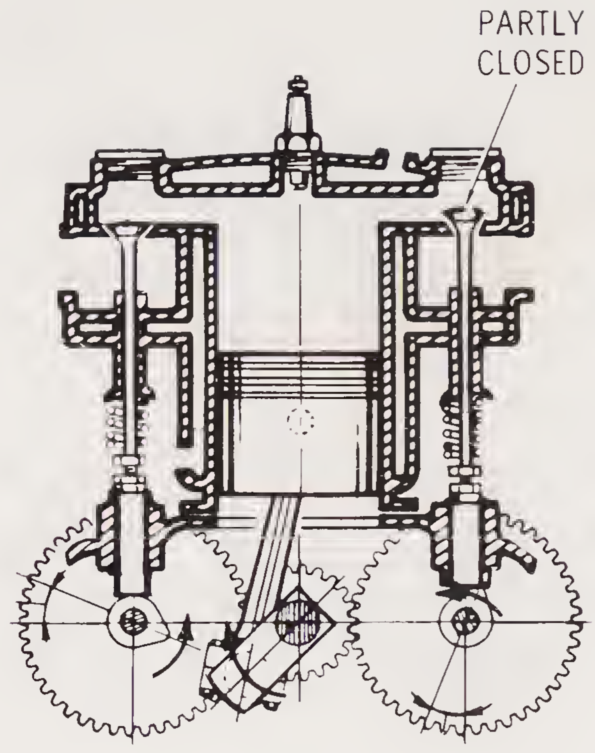


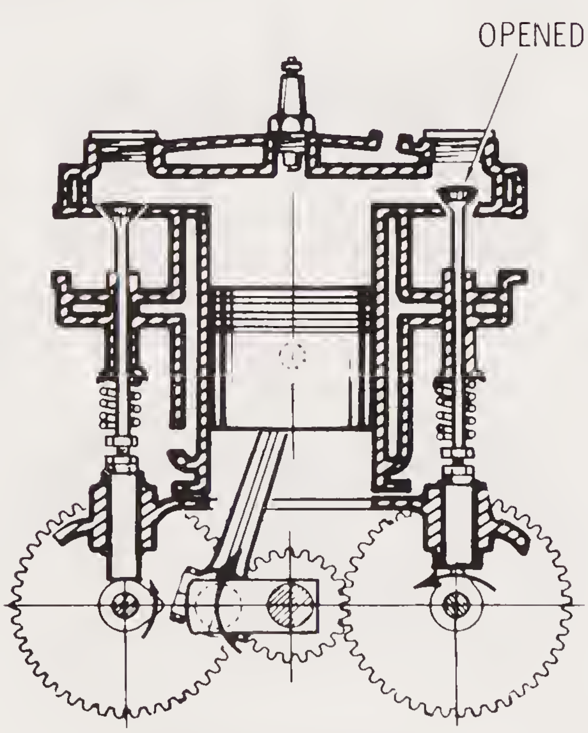

**Fig. 1-8. The power stroke in a four-stroke engine.**



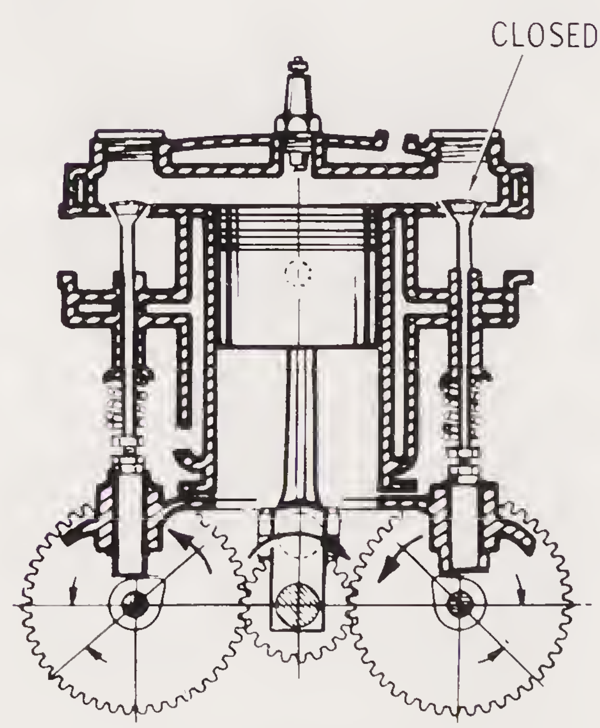

Beginning of Stroke




Crank at 45 Degrees




Crank at 90 Degrees




End of Stroke

**Fig. 1-9. The exhaust stroke in a four-stroke engine.**

## Valve Overlap

In the foregoing series of illustrations it was assumed that the valves begin to open when the piston passes its dead center, but this, however, is not the case in the highly developed high-speed engines. To compensate for the time required by the air-fuel mixture and exhaust to flow through the manifold, the valves are timed to overlap a certain amount, the amount of overlap depending upon the design and speed of the engine.

In theory, the intake valve should open at the exact time the piston starts down in the cylinder and should close at the instant the piston starts upward in the cylinder on the compression stroke. Both the intake and exhaust valves should remain closed during compression and power, and the exhaust valve would then open at the end of the power stroke and close at the end of the exhaust stroke. Such an arrangement may be satisfactory for a slow-speed engine, but with increased speed a certain amount of valve overlap is necessary to obtain better cylinder charging.

## Power Output

In our discussion of the fundamental principles of operation, it will be noted that the two-stroke-cycle engine delivers twice as many power impulses to the crankshaft as the four-stroke engine in the same number of crankshaft revolutions. Theoretically, then, the two-stroke-cycle engine would have twice the power output of a four-stroke-cycle engine of the same size. This, however, is not true because of the waste in fuel and power when some of the incoming fuel mixture combines with the exhaust gases and goes out with them. The volumetric efficiency of the two-stroke-cycle engine is thus reduced to some extent.

## Comparison of Engines

As previously noted, the two-stroke-cycle engine has the advantage of extreme simplicity, owing to the absence of valves or other moving parts. This valveless feature of the two-stroke-cycle type, while providing simplicity, will at the same time give rise to certain irregularities in the action of the engine.

The action of the gas in the cylinder is somewhat uncertain, since it is hardly to be expected that the inflow of gas will continue exactly long enough to fill the cylinder. Because of this it is entirely possible that either some of the exhaust gases may not have time to escape or that some of the fresh charge may pass over and out through the exhaust port.

There are also more disadvantages that may be termed structural. Intake and exhaust ports of a two-stroke-cycle engine are cut into the cylinder wall instead of in the top of the combustion chamber as in a four-stroke-cycle engine, leading to extra piston and ring wear. As the crankcase must be gas-tight, any leakage around the crankshaft bearings causes a pressure loss with consequent loss of power. Also, any leakage around the piston will allow the partially burned gases to pass down and deteriorate the quality of the fresh fuel-air mixture in the crankcase.

The four-stroke-cycle engine, although more complicated, is more dependable in its action, as the behavior of the gas is mechanically controlled. Owing to the mechanical regulation there is less chance of fuel waste, and the economy is therefore somewhat greater than that of the two-stroke-cycle type.

As a general conclusion it may be stated that for small, light engines that receive little attention and where economy is not of great importance, the two-stroke-cycle engine is preferred. For a single-cylinder engine, the two-stroke-cycle type may also be preferable because the vibration is often less than in the single-cylinder engine of the four-stroke-cycle type.

For engines of larger size, where increased reliability and fuel economy is an important factor, the four-stroke-cycle engine is preferable.

CHAPTER 2

# Classification of Engines

Gas engines may be classified by one or more of the following: according to cycle arrangement (two-stroke or four-stroke), type of cooling system, number and arrangement of cylinders, and valve mechanism type and arrangement.

## BY COOLING

Engines may also be classified as to whether they are air or liquid cooled. All engines are cooled by air to some extent, but air-cooled engines are those in which air is the only external cooling medium. Lubricating oil and fuel assist somewhat in cooling all engines, but there must be an additional external means of dissipating the heat absorbed by the engine during the power stroke.

### Air Cooled

Air-cooled engines are used extensively for lawn mowers, motorcycles, small aircraft and portable equipment. This type of engine is employed where there must be an economy of space and weight, since it does not require a radiator, water jacket or pump to circulate the coolant.

In air-cooled engines, the cylinders are cooled by conduction of heat to metal fins on the outside of the cylinder wall and head. To accentuate the cooling, air is circulated between the fins. Also, when possible, the engine is installed so that it is exposed to the air stream of the vehicle or appliance and has baffles to direct the air over the fins. If the engine cannot be mounted in the air stream, a fan is customarily employed to force the air across the fins.

### Liquid Cooled

Liquid-cooled engines are those that require a water jacket to hold the coolant around the valve ports, combustion chambers and cylinders, a radiator to dissipate the heat from the coolant to the surrounding air and a pump to circulate the coolant through the engine. Liquid-cooled engines may also require a fan to draw air through the radiator for proper dissipation of heat.

## BY VALVE ARRANGEMENT

Four-stroke-cycle engines may be classified according to the position of the intake and exhaust valves, that is, how they are located in the cylinder block or in the cylinder head. Various arrangements have been used, but the most common are the in-block L and T and overhead-I designs. The letter designation is used because the shape of the combustion chamber resembles the form of the letter identifying it.

### L-Head

The L-head as shown in Fig. 2-1, has both valves on the same side of the cylinder. The valve-operating mechanism is located directly

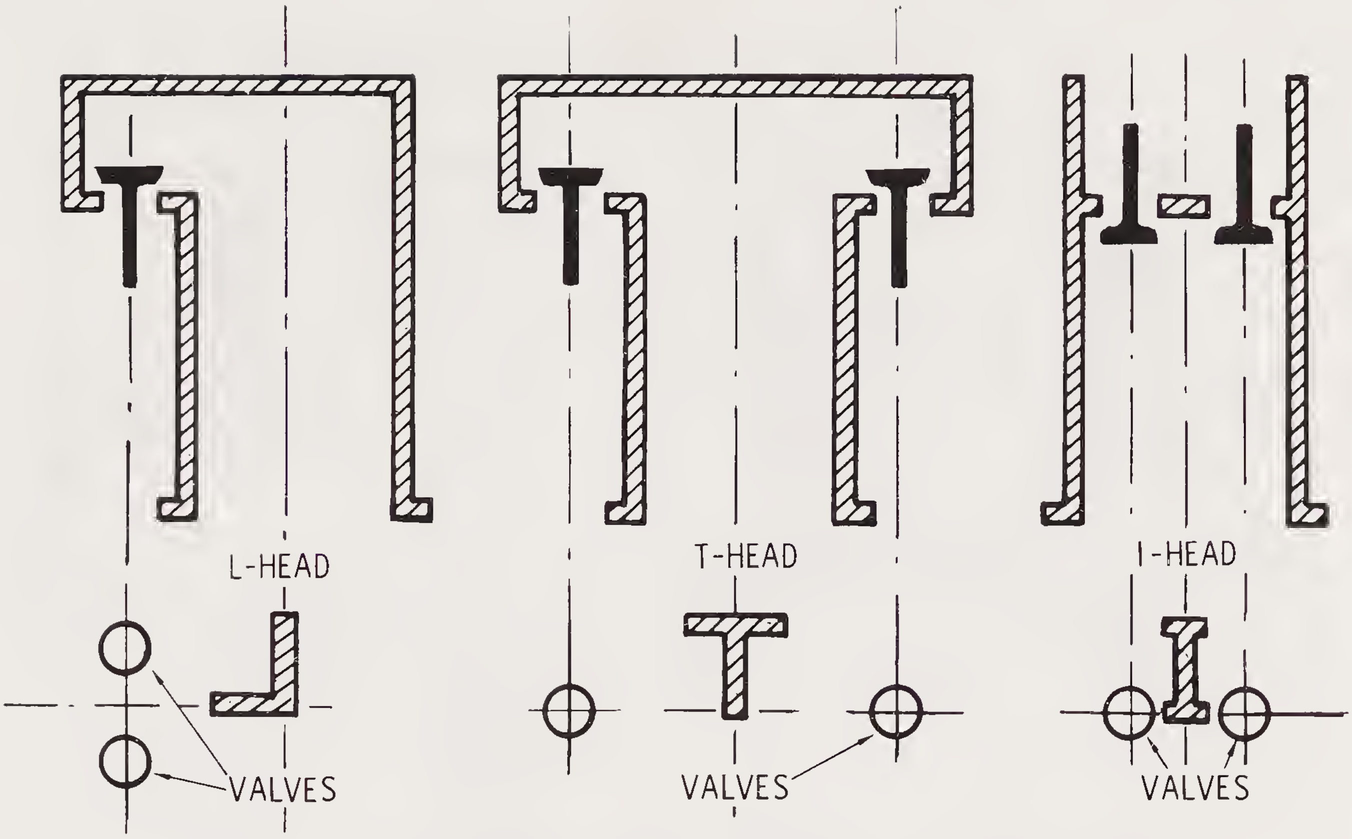



**Fig. 2-1. Valve arrangement for various types of engines.**

below the valves, and one camshaft serves both the intake and exhaust valves.

## T-Head

The T-head type of valve arrangement, Fig. 2-1, has one or more intake valves on one side, with the exhaust valve or valves on the opposite side of the cylinder. This type of arrangement has been largely supplanted by the L-head, the disadvantage of the T-head being that two complete valve operating mechanisms were required.

## I-Head

Engines employing the I-head construction, Fig. 2-1, are commonly termed "valve-in-head" or "overhead" valve engines, because both the intake and exhaust valves are mounted in the cylinder head above the cylinder. This arrangement requires a push rod and a rocker arm or top-mounted camshaft above the cylinder, but only one camshaft is required for both valves, as noted in Fig. 2-2.

Each of the foregoing valve arrangements has certain advantages and disadvantages, although the I-head or "valve-in-head" type

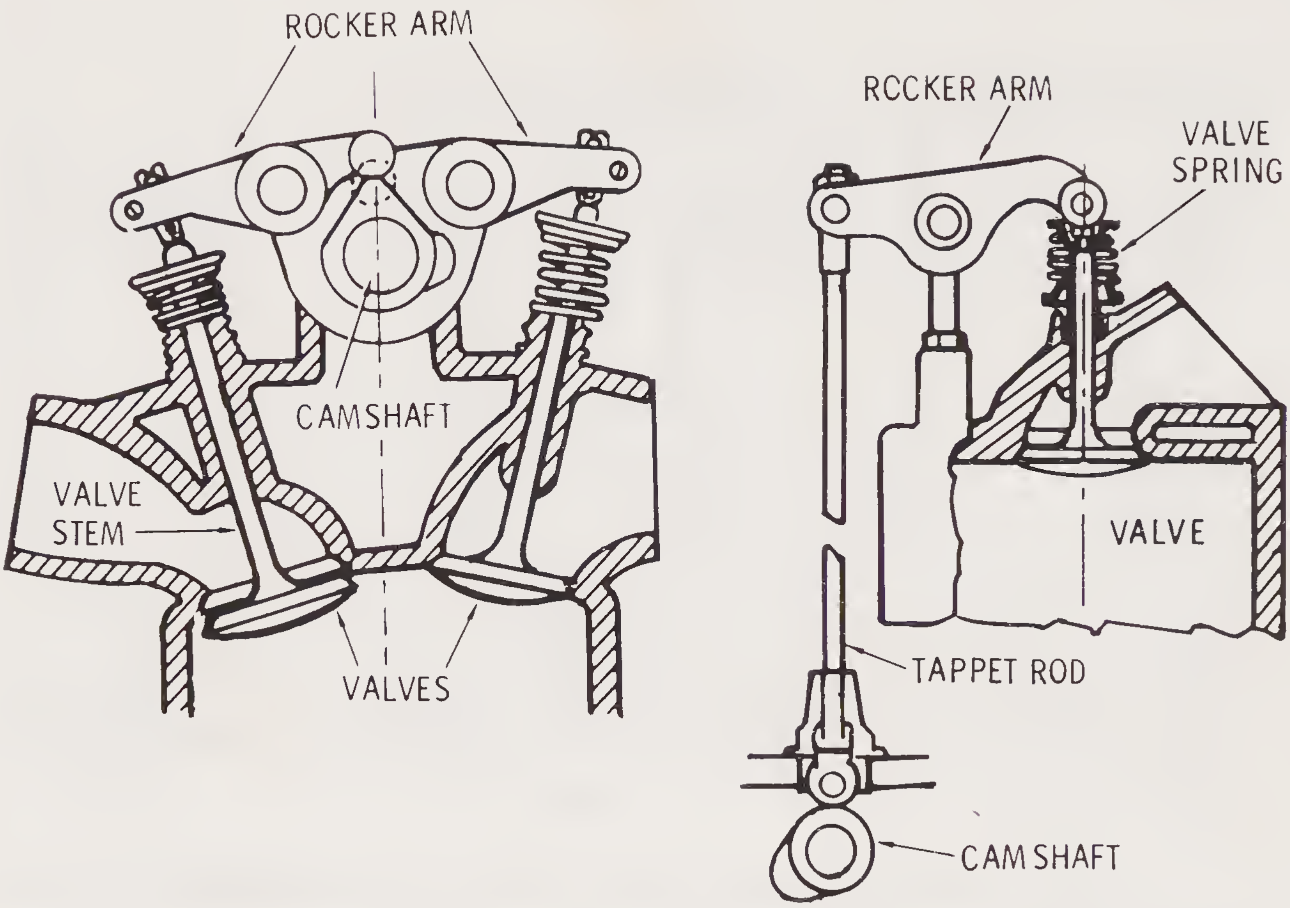



**Fig. 2-2. Overhead camshaft with rocker arms (*left*); and overhead valves operated by tappet and pushrods from camshaft (*right*).**

is favored because it provides the most efficient distribution of the charge in and out of the cylinder, making it the best arrangement for obtaining maximum power.

## MULTICYLINDER ENGINES

The number of cylinders required in a particular engine depends upon its size and application. Due to the fact that the four-stroke-cycle gas engine delivers only one power stroke in two revolutions of the crankshaft, causing excessive vibration, it would be very objectionable in automotive service. Hence modern practice in automotive and similar applications is to divide the power between several cylinders.

In early automotive applications, one-cylinder, two-cylinder and some three-cylinder power plants were used, but the many advantages of a larger number of cylinders soon led to their adoption throughout the industry.

Among the disadvantages of one- or two-cylinder engines are:

1. The uneven turning.
2. Excessive vibration.
3. Large cylinders required.
4. Tendency to stall.

In order to overcome these defects, additional cylinders were provided. Thus, for a time the four-cylinder engine reigned supreme; then came engines with six, eight, twelve and even sixteen cylinders.

It is usually impracticable, however, to employ more than eight cylinders in automotive application on account of the greater length of the power plant and the much stronger and heavier crankshaft required. As the number of cylinders is increased, the solution for the best arrangement is found in two sets of cylinders inclined at an angle, thus providing an engine of shorter length. This engine is called the V-type. In this type of engine the angle between the cylinders usually is either 90°, 75°, 60° or 45°. The advantages of multiple cylinders are:

1. More even turning.
2. Less vibration.
3. Smaller cylinders and block.
4. Flexibility of application.

To understand clearly the necessity for multicylinder engines where larger amounts of power are required, the comparison of a four-cylinder engine with a one-cylinder engine of equal power will be considered.

*Example.* Assume the four-cylinder engine has a 3-in.-diameter cylinder. Its area is 7.07 sq. in. and if the pressure of combustion is 300 lb., then the sudden piston load will be $7.07 \times 300$ or 2121 lb.

The piston of a single-cylinder engine of equal horsepower must consequently be four times the area of the four-cylinder engine, or $7.07 \times 4 = 28.28$ sq. in. The load absorbed by the piston at ignition would in this latter case be $28.28 \times 300$ or 8,484 lb.

Now, since the piston in the single-cylinder engine will be four times larger in area for the same power and pressure per square inch, it follows that the parts of the single-cylinder engine must be

much heavier than those of the four-cylinder engine. Also, a single-cylinder engine would easily stall if a sudden load were applied, owing to the intermittent nature of the torque. This defect has been partly eliminated by the addition of cylinders. The use of the greater number of cylinders has resulted in a more flexible engine.

Because of constantly increasing gasoline taxes, the present tendency toward a more economical engine has resulted in the development of automotive engines with fewer than eight cylinders and less power. Thus, at the present time, four- and six-cylinder engines are again gaining favor, resulting in smaller and more compact engines for lighter cars.

## BY CYLINDER ARRANGEMENT

Gas engine cylinders also vary in their arrangement. Cylinder arrangement in engines is usually *in line*, *V-type* or *opposed*.

### In-Line

The vertical in-line cylinder arrangement is one of the most commonly used types. In a design of this sort, all the cylinders are cast or assembled in a straight line above a common crankshaft. See Fig. 2-3.

### V-Type

In the V-type engine (Fig. 2-3) two "banks" of in-line cylinders are mounted in a V-shape above a common crankshaft. This type is designated by the number of degrees contained in the angle between the banks of cylinders. In automotive use, the angle of the V is usually 90° for eight- and many six-cylinder engines; 75°, 60° or 45° for newer six- and twelve-cylinder engines. Crankshafts for V-type engines generally have only half as many throws as there are cylinders, since two conecting rods, one for each bank, generally are connected to each throw.

### Horizontally Opposed

The horizontally opposed engine (Fig. 2-4) has its cylinders placed horizontally in two rows 180° apart with the crankshaft mounted in

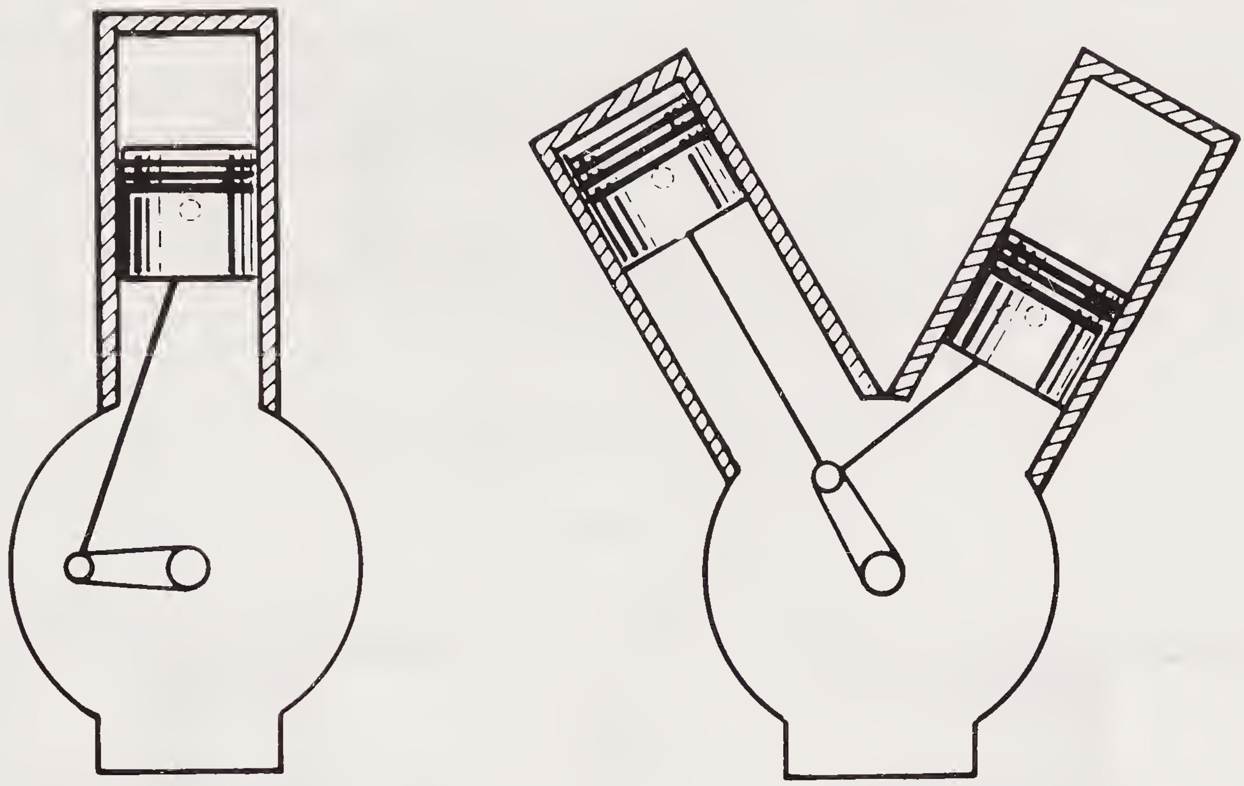



**Fig. 2-3. Illustrating the cylinder arrangement in vertical (in-line) and V-type engines.**

the center. This type of cylinder arrangement is used primarily to conserve space, lower the center of gravity and decrease weight.

## FIRING ORDER

There are two possible firing orders or methods of timing for four-cylinder engines, as 1-2-4-3 and 1-3-4-2, the latter being the most widely used. See Fig. 2-5.

With six-cylinder engines, there are seven possible firing orders. In-line designs most commonly use 1-5-3-6-2-4, but may also use 1-4-2-6-3-5 or 1-3-2-6-3-5. While many V-type six-cylinder engines use the popular 1-5-3-6-2-4 arrangement, a few have used 1-2-3-4-5-6 and many new styles have changed to 1-6-5-4-3-2.

Eight-cylinder engines have used two different sequences. The most popular eight-cylinder firing order is 1-8-4-3-6-5-7-2, while other designs have used 1-5-6-3-4-2-7-8.

The order in which the cylinders will fire depends upon the sequence of cranks and cams and the ignition hookup. The construction is such that they will not usually fire in consecutive order

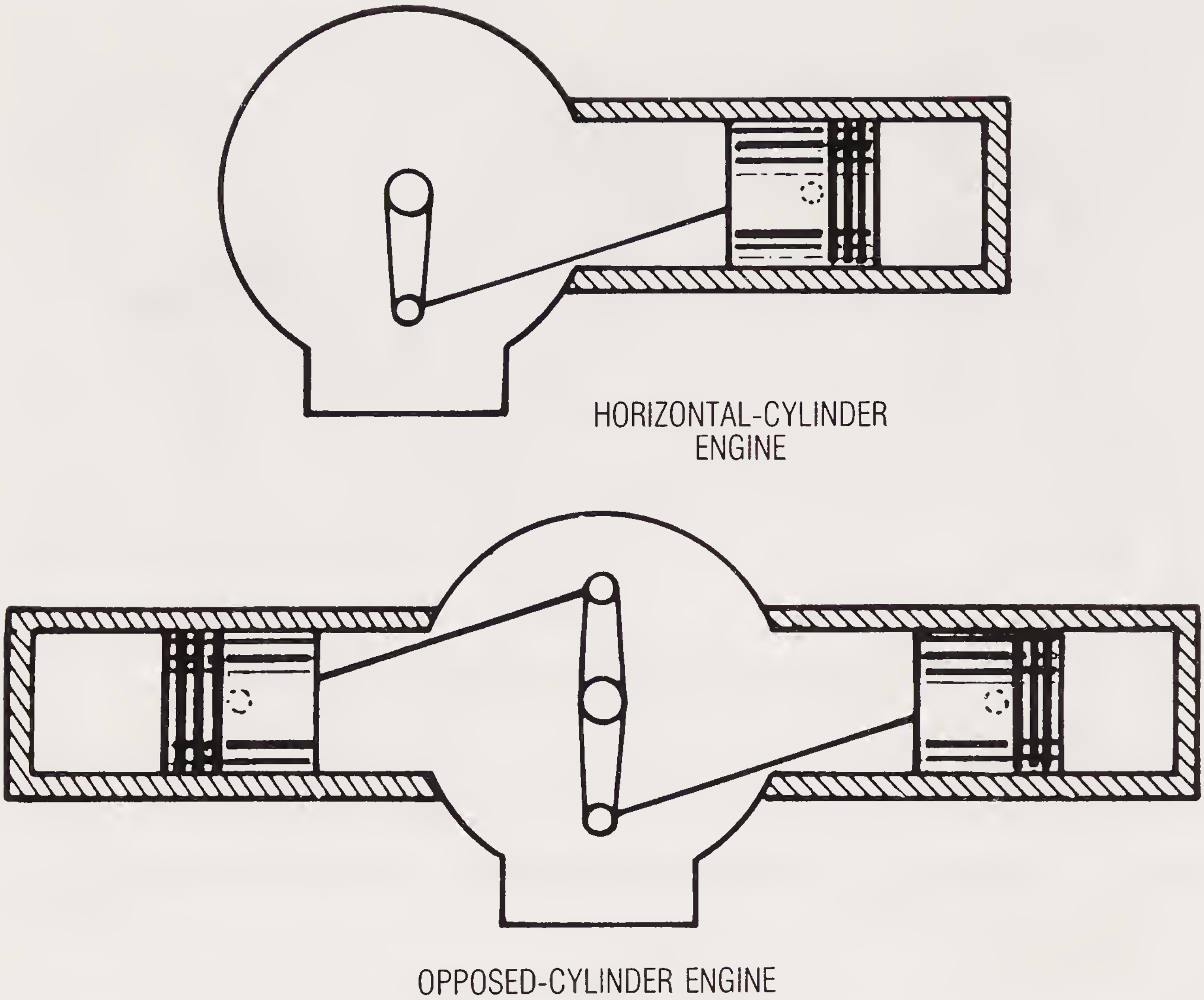



**Fig. 2-4. Horizontal and horizontally opposed cylinder arrangement.**

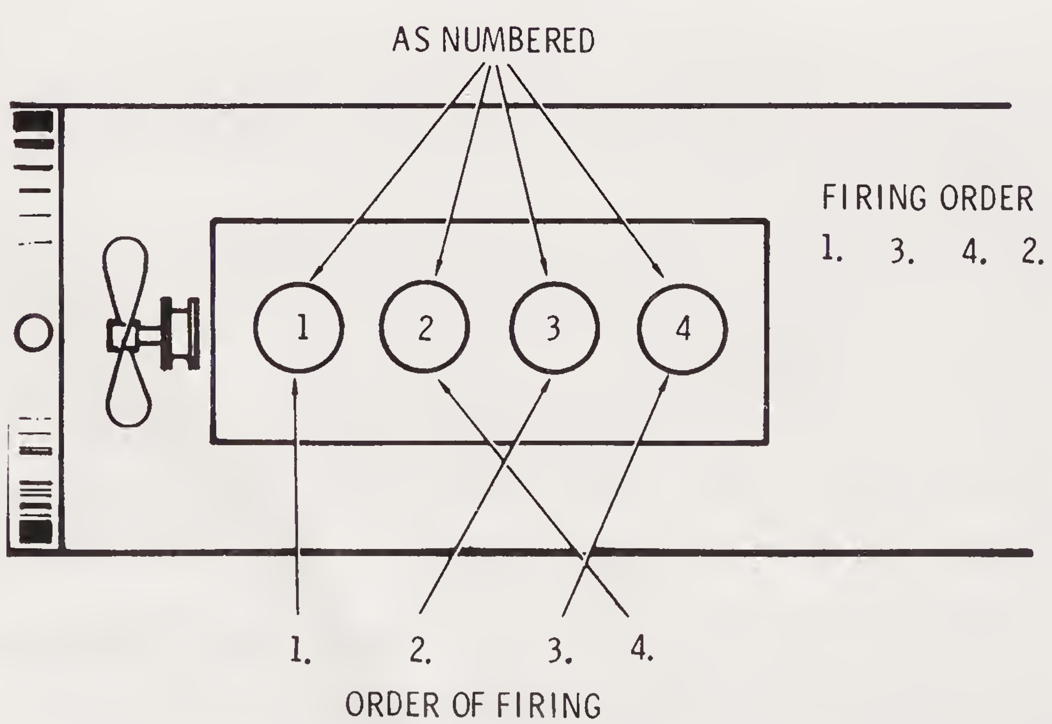



**Fig. 2-5. Typical firing order of a four-cylinder engine.**

from front to rear of engine, but in some other order selected by the engine designer, the object being to reduce vibration as much as possible.

Of Special Note. All firing orders have been expressed in crankshaft notation, from the front to the rear of the engine. Some engine manufacturers, such as Ford Motor Company, have numbered their V-type engines using cylinder notation, which counts down the right bank, then the left.

CHAPTER 3

# Gas Engine Parts

In the preceding chapters, the gas engine has been treated with respect to its principles of operation, the explanations being accompanied by elementary diagrams. Drawings of this kind, however, do not show the construction details but only the principles upon which the engine operates.

In this connection it should be noted that due to the various services to which a gas engine is being put, the designs will vary greatly as will the component parts; the operating principles, however, will in each instance be similar.

The various parts which make up the engine proper may be classed as:

1. **The stationary parts:**
    a. Cylinders
    b. Crankcase or block
    c. Cylinder head
    d. Manifolds

2. **The moving parts:**
   a. Pistons
   b. Connecting rods
   c. Crankshaft
   d. Flywheel
   e. Valves
   f. Valve gear

In addition to these parts, various systems are added to the engine as shown in Figs. 3-1, 3-2, 3-3, and 3-4:

1. **Fuel system**
2. **Ignition system**
3. **Lubrication system**
4. **Cooling system**

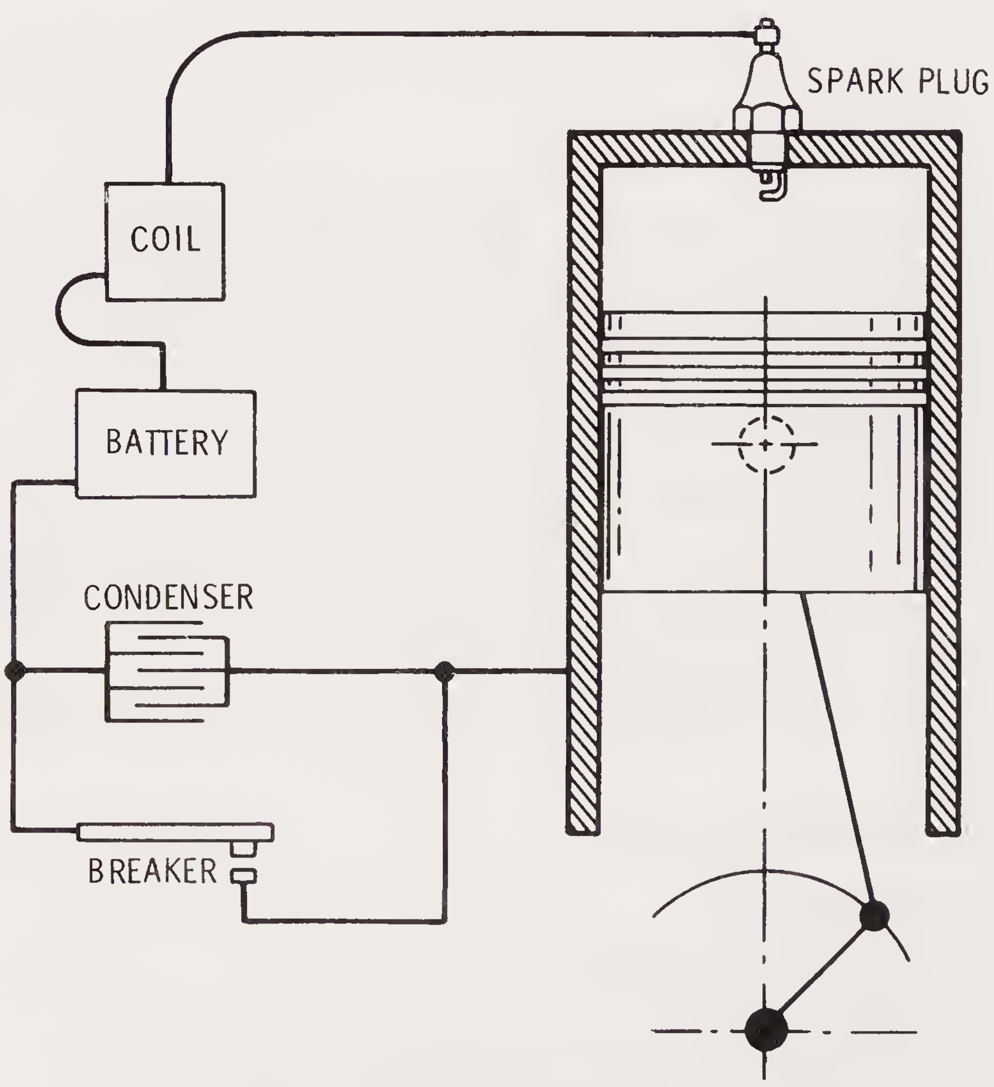



**Fig. 3-1. Ignition system.**

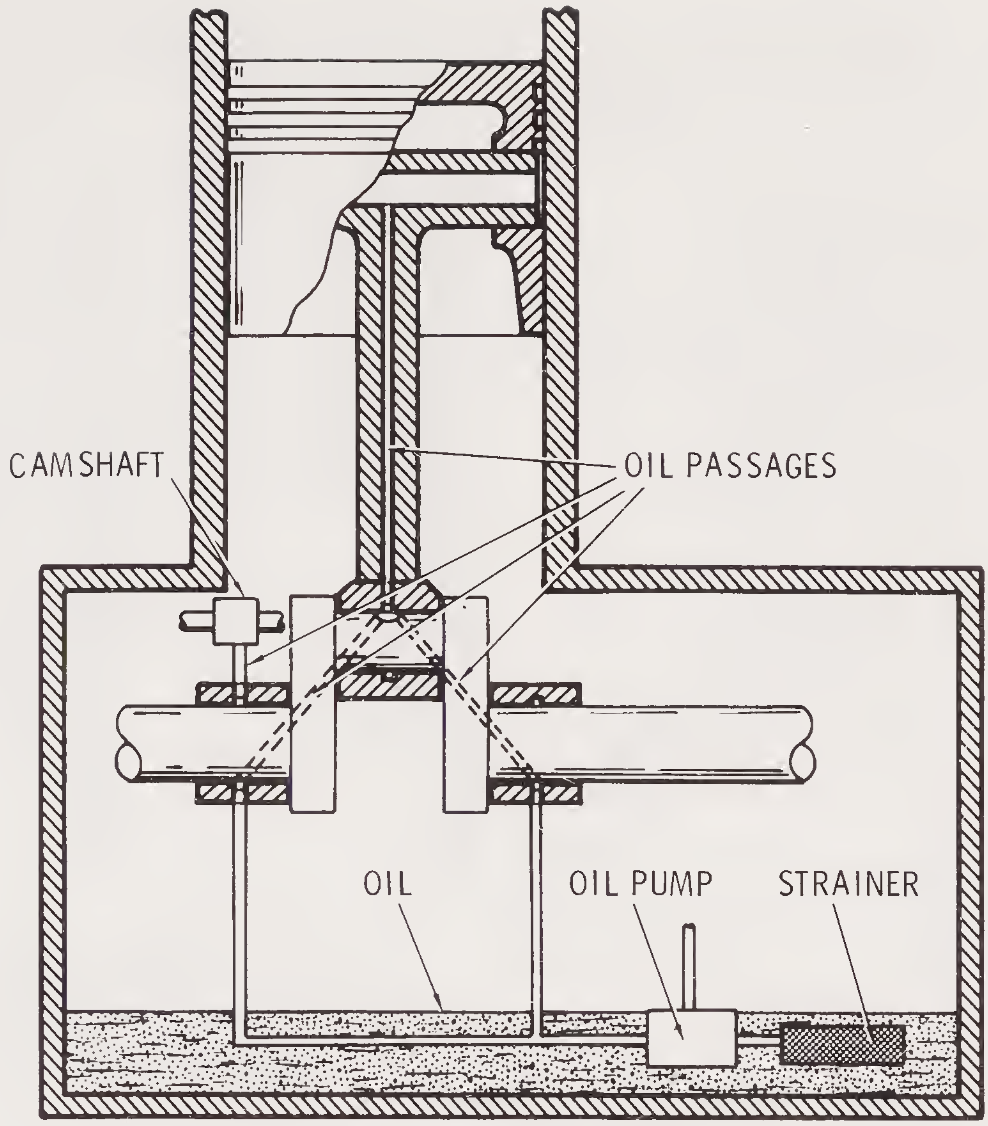



**Fig. 3-2. Lubrication system.**

## STATIONARY PARTS

In the makeup of a gas engine the main stationary parts are: (1) the cylinder casting, (2) the crankcase (3) the cylinder head and (4) the oil pan.

### Combined Cylinder and Crankcase Casting

In late engine construction, the practice has been in most cases to combine these two parts in one casting; that is, the cylinder and crankcase are cast *in-block* or in one piece called the cylinder block. The advantages of the in-block method are so numerous that it has become almost universal. Casting cylinders in-block produces more compact, shorter, and more rigid construction at less cost than cast-

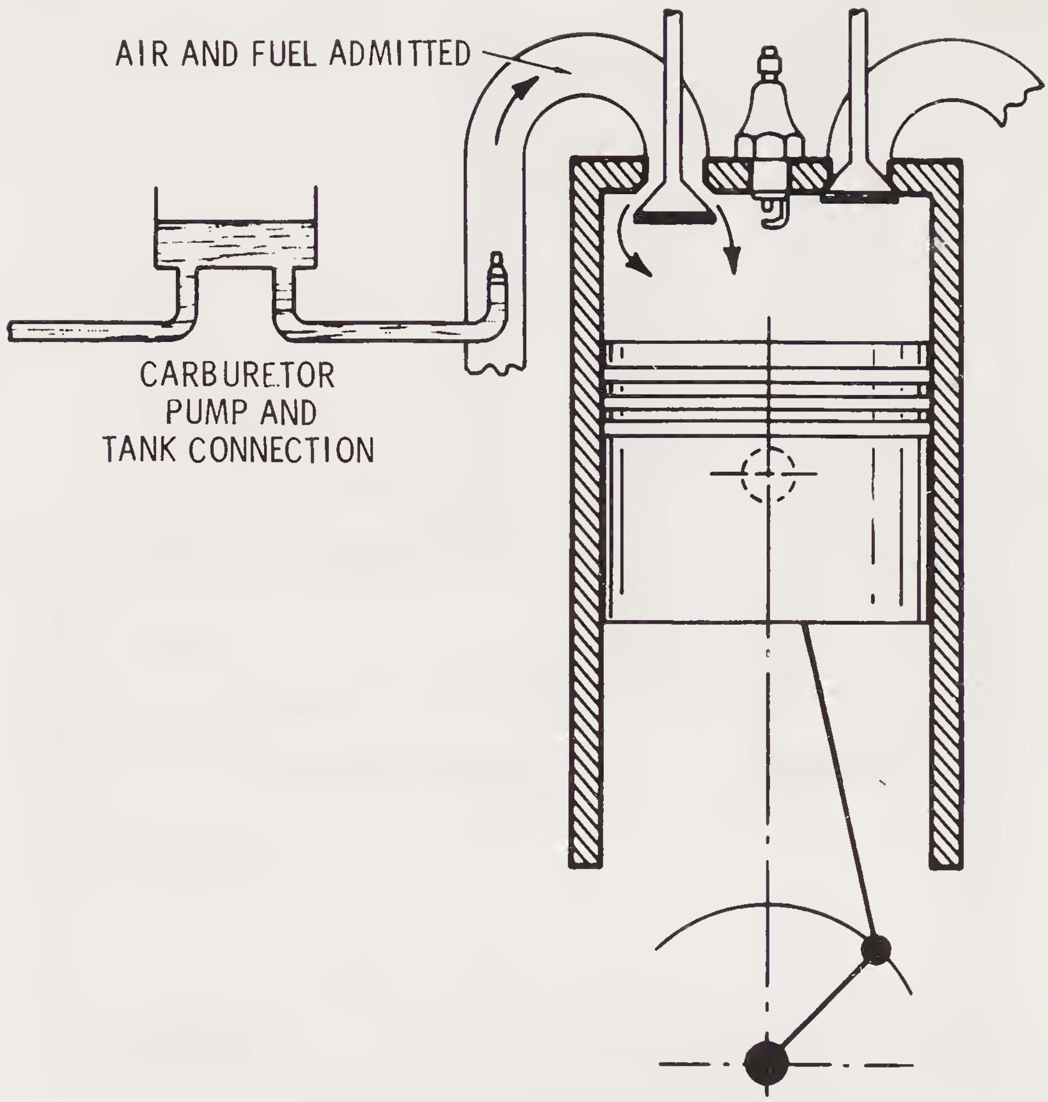



Fig. 3-3. Fuel system.

ing cylinders singly or in pairs. It also simplifies the assembly and provides for a simplified enclosure of the valve-operating mechanism.

In the in-block design, the crankcase is usually extended a short distance below the centerline of the crankshaft. This construction is what is known as the *split* type of crankcase, that is, the lower part enclosing the bottom of the crankcase or oil pan is separated and bolted to the lower flange of the crankcase, as distinguished from the *barrel type*, in which the lower part is integral.

## Cylinder Head

The cylinder head is a detachable portion of the engine, fastened securely to the cylinder block. It contains passages that match those of the cylinder block and allow the coolant to circulate in the head. All cylinder heads were formerly made of cast iron, but numerous engines are now being built with cylinder heads of cast aluminum

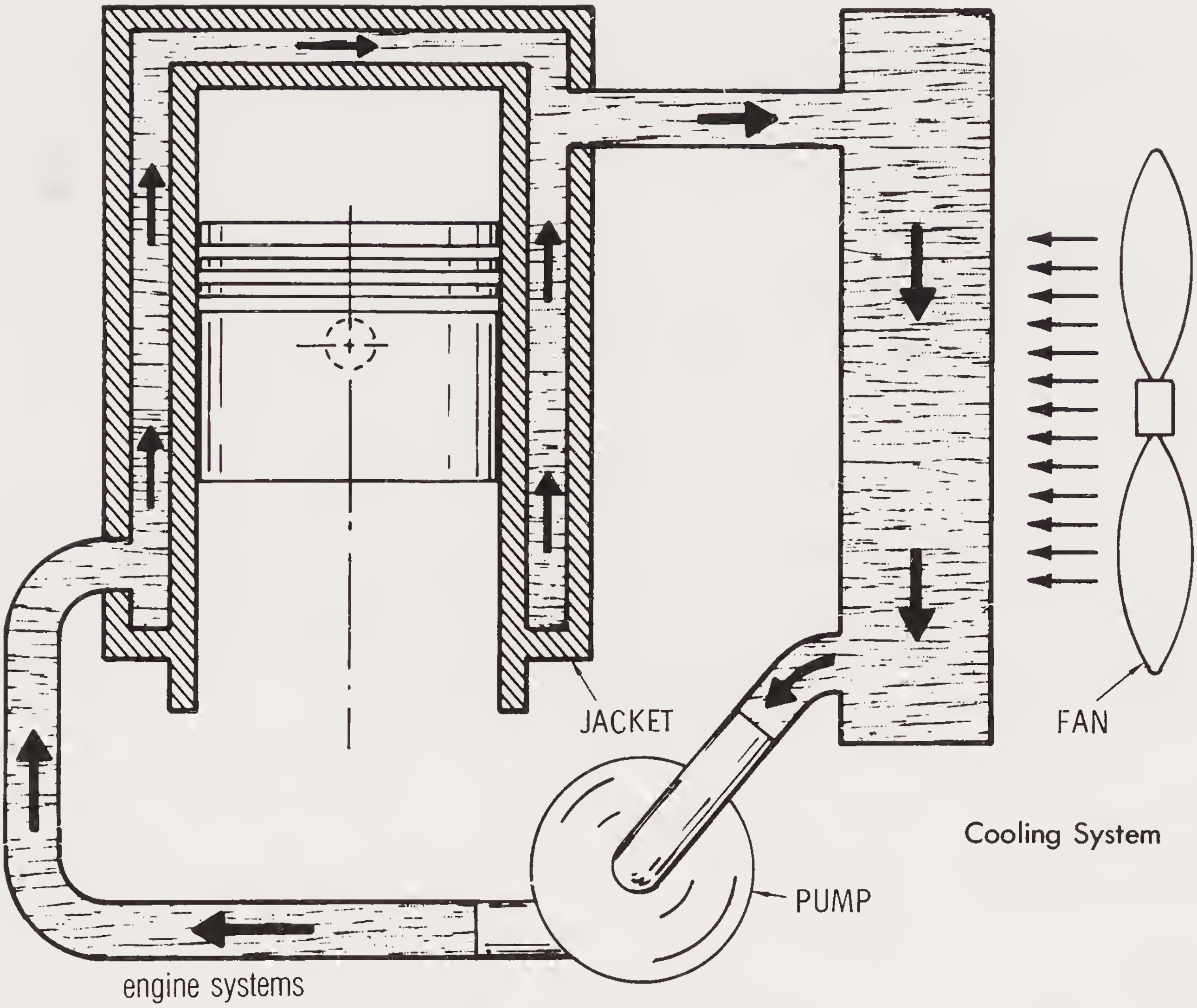



Fig. 3-4. Cooling system.

alloy because of its better conduction of heat, thus providing improved engine cooling.

### Manifolds

Passageways, which are cast into precision-fit bolted-on castings, are used to direct the fuel-air mixture to the cylinders and also to the exhaust away from the cylinders. These passageways are known as manifolds. Except for the possible addition of a heat-control valve in the exhaust manifold, they contain no moving parts.

## MOVING PARTS

The various moving parts that act to transform the energy contained in the incoming fuel mixture finally into useful power may be classed as:

1. **The reciprocating parts:**
    a. Piston
    b. Connecting rod
    c. Valve gear
2. **The rotating parts:**
    a. Crankshaft
    b. Camshaft
    c. Auxiliary shafts, for pump operation, etc.

The degree of perfection in operation of the engine depends largely upon the proper proportion and efficient arrangements of these parts and is an index of the engineering ability of the designer of the engine.

# CHAPTER 4

# Pistons

The piston is one of the most important parts of the engine mechanism. For the gas engine, it consists essentially of a cylindrical casting, closed at the top and open at the bottom end, having attached at an intermediate point a wrist pin which transmits the thrust, due to the burning gases, to the connecting rod and thence to the crankshaft.

A piston performs the following duties:

1. It transforms heat energy into mechanical energy.
2. It transmits the lateral thrust, due to the angularity of the connecting rod, to the cylinder walls.
3. It carries off some of the excessive heat generated in the combustion chamber.

Pistons employed in early engines were crude affairs, as compared with late designs. The improved designs are a result of the

requirements becoming more and more severe to meet the needs of increased piston speeds and higher compression and combustion pressures.

## PISTON REQUIREMENTS

The design of the piston is controlled to some extent by the design of other parts of the engine, and this accounts for the fact that all engines do not use the same kind of piston. One problem with respect to piston design is to produce a piston that will run with the minimum amount of clearance. See Fig. 4-1.

## PISTON MATERIALS

The materials commonly used in the manufacture of pistons are (a) cast iron and (b) aluminum alloy (most popular).

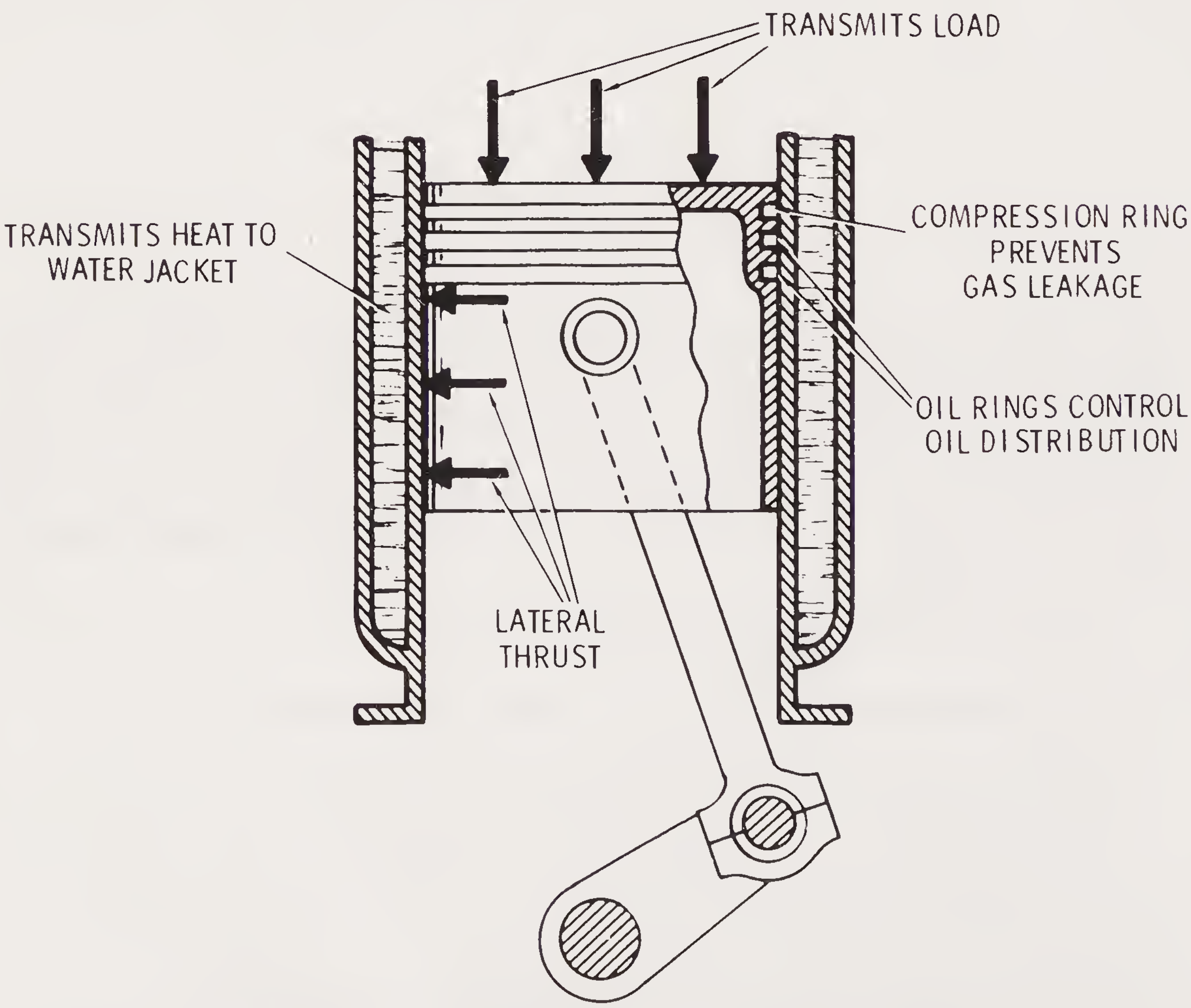



**Fig. 4-1. Typical water-cooled cylinder assembly.**

## Cast-Iron Pistons

The trouble with cast iron for pistons is its weight, being nearly three times as heavy as aluminum alloy. Moreover, it is not as good a heat conductor as aluminum alloy.

Formerly, before engine speeds and compression became as great as they are now, the above properties of cast iron were not so objectionable. However, a heavy piston running at several thousand strokes per minute has considerable inertia; that is, great force must be applied to start and stop the piston at the ends of the stroke, resulting in excessive vibration and greater stresses on the bearings.

To reduce vibration and heavy stresses, attempts were made to make the piston as light as possible by the rib construction. The ribs extending across the head and down the skirt were depended on almost entirely for strength.

An advantage of cast-iron pistons is that they have the same rate of expansion as the cylinder and therefore can be fitted with minimum clearance.

## Aluminum-Alloy Pistons

A desirable characteristic of the aluminum-alloy piston is its lightness. In modern, high-speed engines, the pistons have to travel up and down, that is, reciprocate, from a few hundred to thousands of times a minute. A weight moving up and down at such high speed requires a great force to stop it and a great force to start it because of its *inertia.*

This force due to inertia is transmitted by the connecting rod to the bearings, and it is this force which pounds against the bearings and produces vibration. It is therefore important that this force be reduced to a minimum. That was the reason for the introduction of aluminum-alloy pistons, since aluminum is very light. All modern engines use aluminum-alloy pistons. See Fig. 4-2.

To reduce the weight of cast-iron pistons they must be made very thin. While this might give the desired lightness, a thin piston offers so much resistance to heat flow that the piston would become unduly hot. Quicker acceleration is possible with aluminum-alloy pistons because of the reduction in weight.

Another advantage is that aluminum is a much better conductor

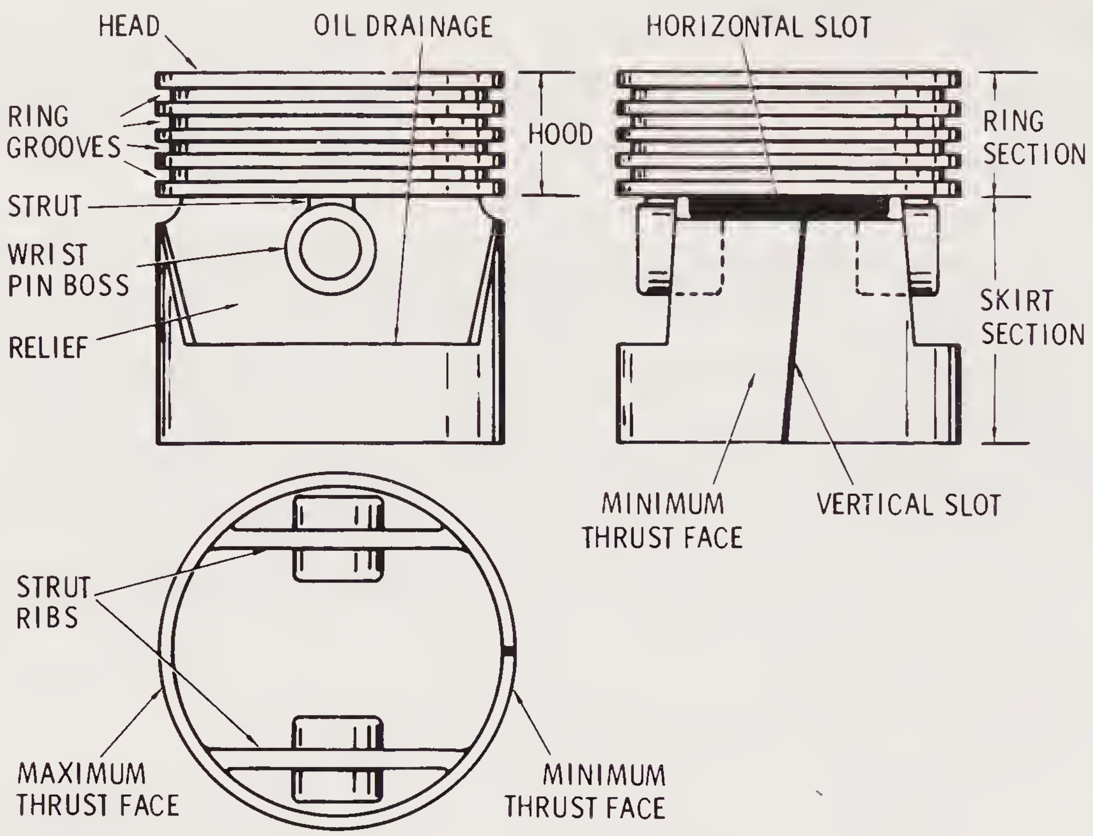



**Fig. 4-2. The various parts of the piston.**

of heat than is iron; hence the temperature of the head of the aluminum piston is lower than that made of cast iron.

A disadvantage is that aluminum alloy expands much more than cast iron with the rise of temperature. As a result, early aluminum-alloy pistons were made with considerable clearance so that they would not be too large at the working temperature. This resulted in piston slap.

## PISTON SLAP

Piston slap is caused by the piston moving from one side of the cylinder to the other. It is a result of the forces acting on the piston changing under influence of the angularity of the connecting rod as illustrated in Fig. 4-3.

During the complete cycle, the piston travels from one side of the cylinder to the other. These changes, however, are rather gradual except at the beginning of the power stroke, which produces the noise known as *piston slap*.

It is not possible to prevent the piston moving from side to side in the cylinder, but the noise due to slapping can be reduced by reducing the clearance. Since aluminum alloy expands at a much

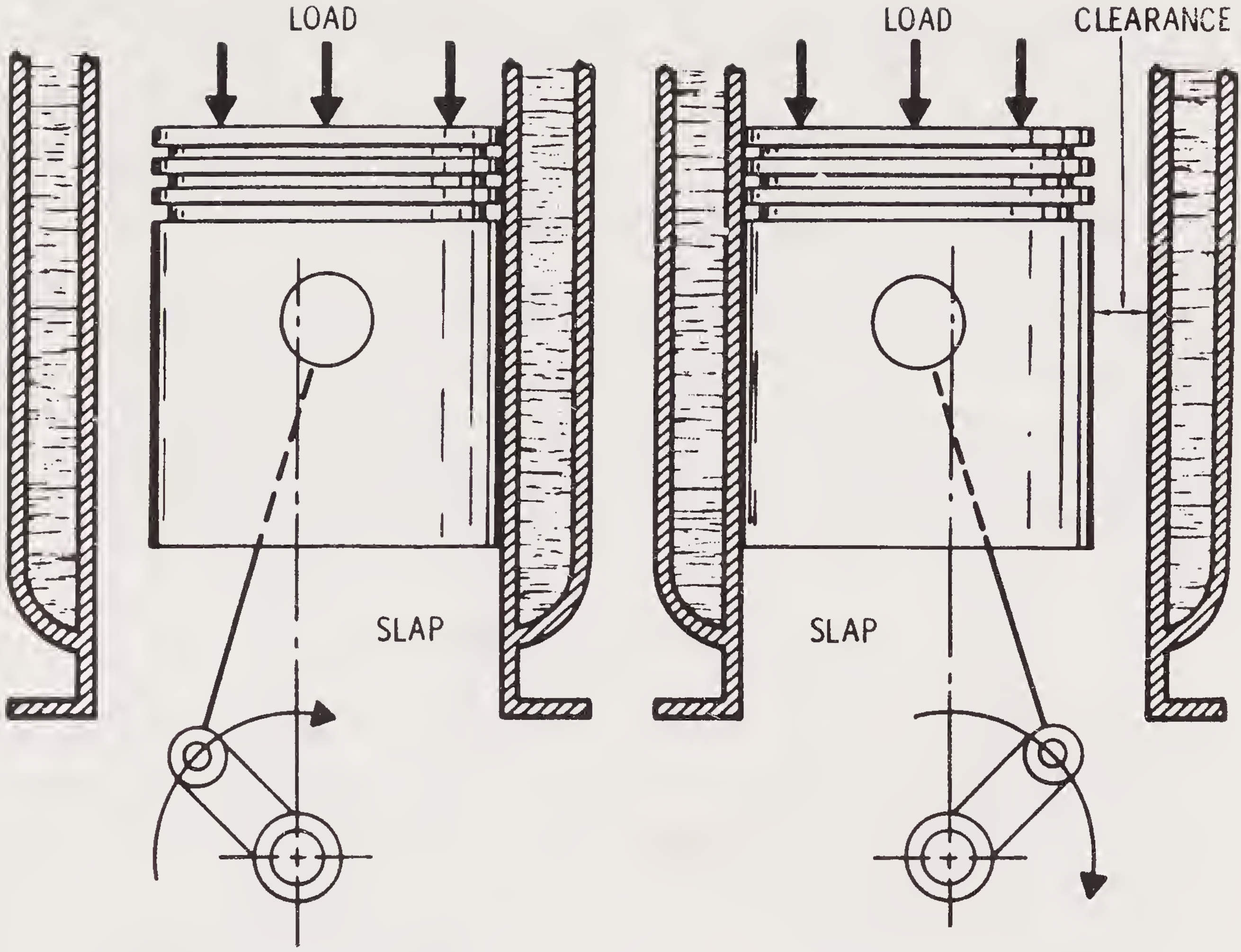



Fig. 4-3. Illustrating piston slap.

greater rate than cast iron when heated, this was not possible in the early solid-skirt aluminum-alloy pistons, but designers overcame this in an improved construction known as the constant clearance piston.

## CONSTANT CLEARANCE PISTONS

It was found that most of the heat that enters the piston leaves through the rings, and that the temperature of the skirt is not high enough to account for all the clearance which was formerly given to aluminum-alloy pistons. The skirt expansion was therefore due to two causes:

1. The expansion caused by the rise in temperature of the skirt.
2. The distortion of the skirt caused by the expansion of the much hotter piston head.

By means of slots in the skirt it has been possible to avoid the

two effects just mentioned, thus producing a piston that will work with a greatly reduced clearance.

By cutting a vertical slot as shown in Fig. 4-4, constant clearance is obtained, with the result that, when heated, the skirt expands circumferentially instead of radially, which causes the diameter of the skirt to remain constant.

The horizontal slot at the top of the skirts partially isolates the skirt from the much hotter ring section and thus avoids distortion by the expansion of the head. By means of ribs connecting the head and wrist pin bosses, the load on the piston head is transferred directly to the wrist pin, thus relieving the skirt of the load.

## COLLAPSE OF SKIRT

As pistons wear, or if they become overheated, the skirt is liable to collapse or become smaller in diameter. This condition will cause piston slap in the cylinder, and high oil consumption due to the increased clearance caused by the collapse of the skirt.

## CAM GRINDING

Most modern aluminum-alloy pistons are *cam ground*, that is, they are purposely machined with the skirts oval. This oval shaping of the piston is intended to compensate for expansion. The reason for this is that the skirts will be slightly oval when cold so that the

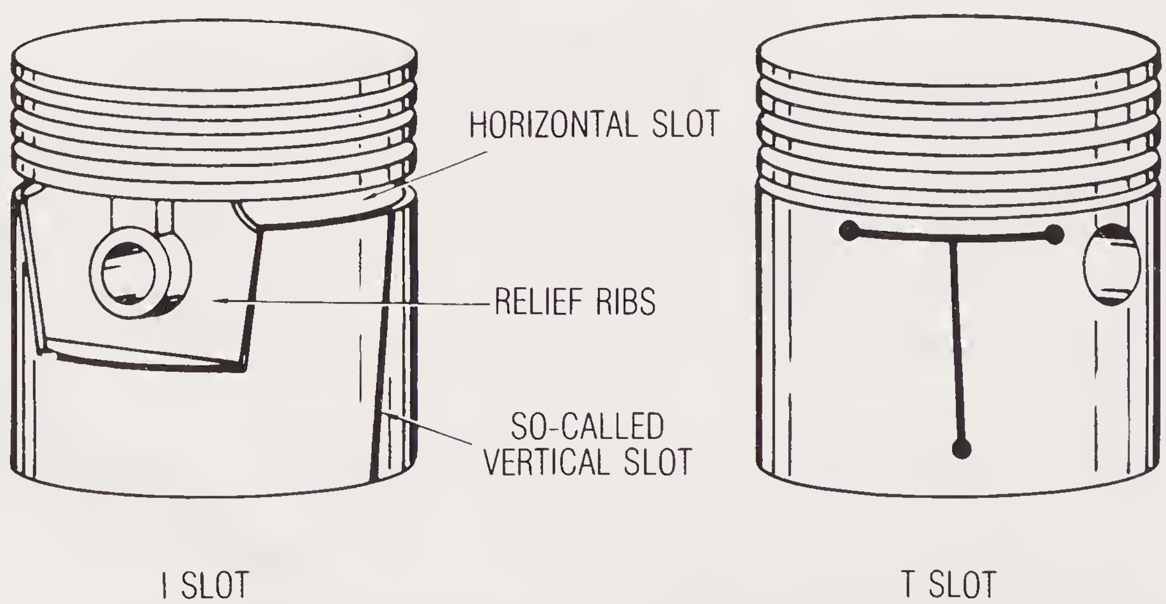



**Fig. 4-4. Piston slots as a means to compensate for skirt expansion due to temperature variations.**

thrust faces will have the greater diameter, but the skirt will become more nearly round when the piston expands at operating temperature (Fig. 4-5).

## T-SLOT PISTONS

This type of piston, shown in Fig. 4-6, is usually used in industrial and truck applications. It combines the features of solid and split

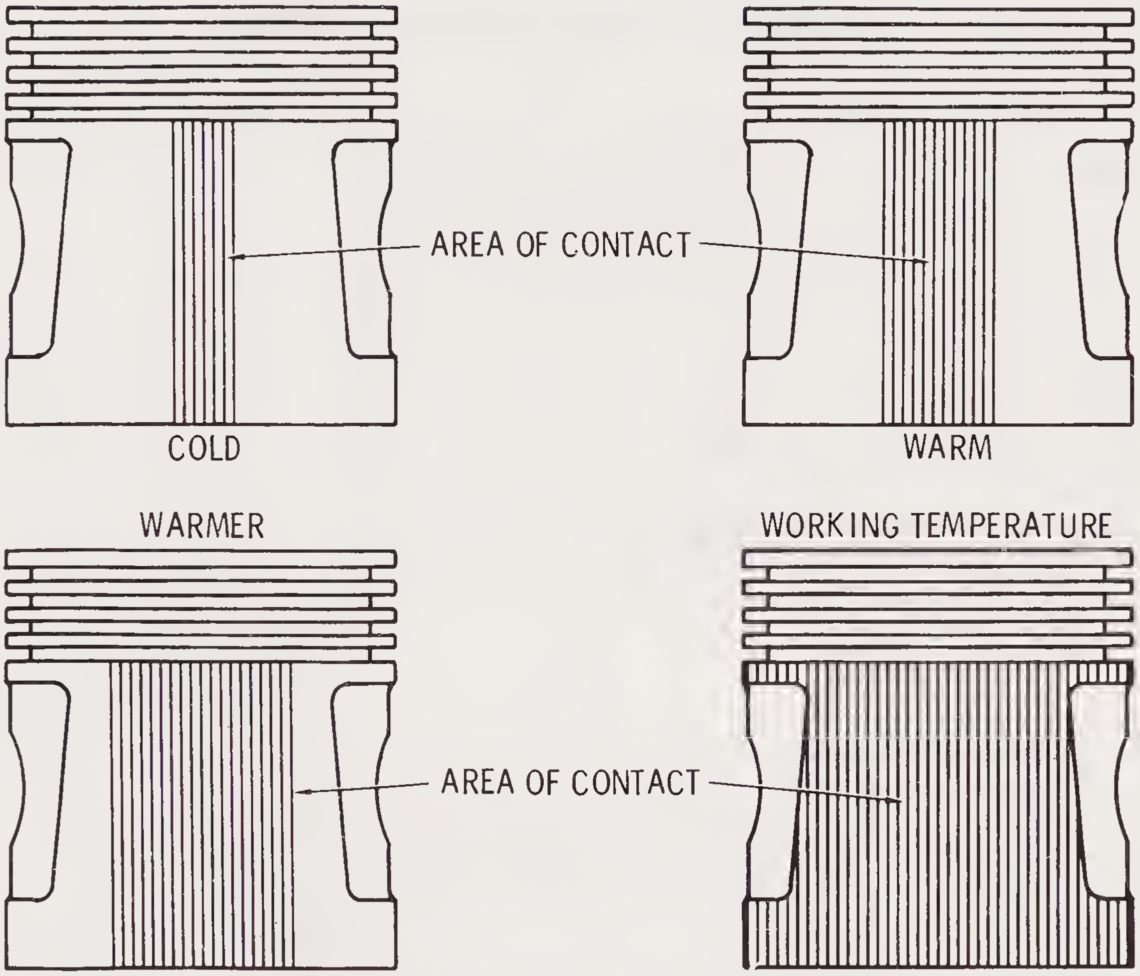



**Fig. 4-5. Variable contact of the piston skirt face with the cylinder walls due to temperature changes progressively shown for the cam-ground piston.**

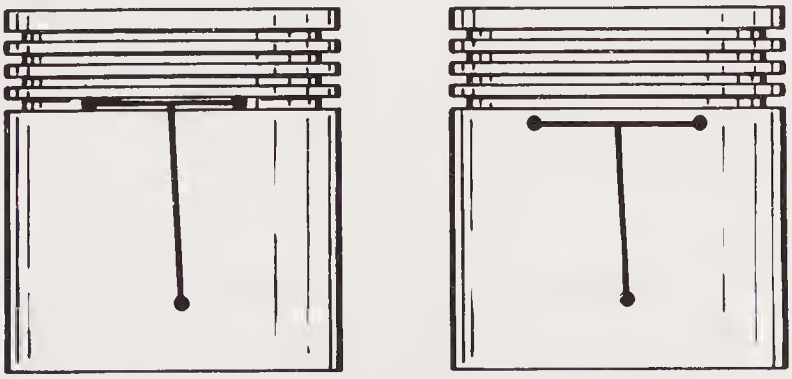


**Fig. 4-6. Two types of T-slot pistons.**

skirts; that is, the vertical slot is not extended all the way to the bottom of the skirt. The term *T-slot* is derived from the resemblance of the two slots to the letter *T*.

As noted in Fig. 4-6, the horizontal slot is placed in the lower groove or near the top of the skirt according to the results aimed at by the designer. Drilled holes are placed at the ends of the slots to prevent possible splitting due to stresses set up by the expansion.

## PISTON TEMPERATURES

There is a great variation in the temperature of different parts of a piston. The hottest part is at the top and the coolest part at the bottom of the skirt. See Fig. 4-7.

The intense heat of combustion naturally heats the head more than other parts. In construction, as a result of this, there must be ample thickness of metal in the head to freely transmit the heat as well as withstand the great pressure to which it is subjected by the combustion of the fuel charge. The head may be flat, concave, convex or a great variety of shapes to promote turbulence or control combustion. See Fig. 4-8.

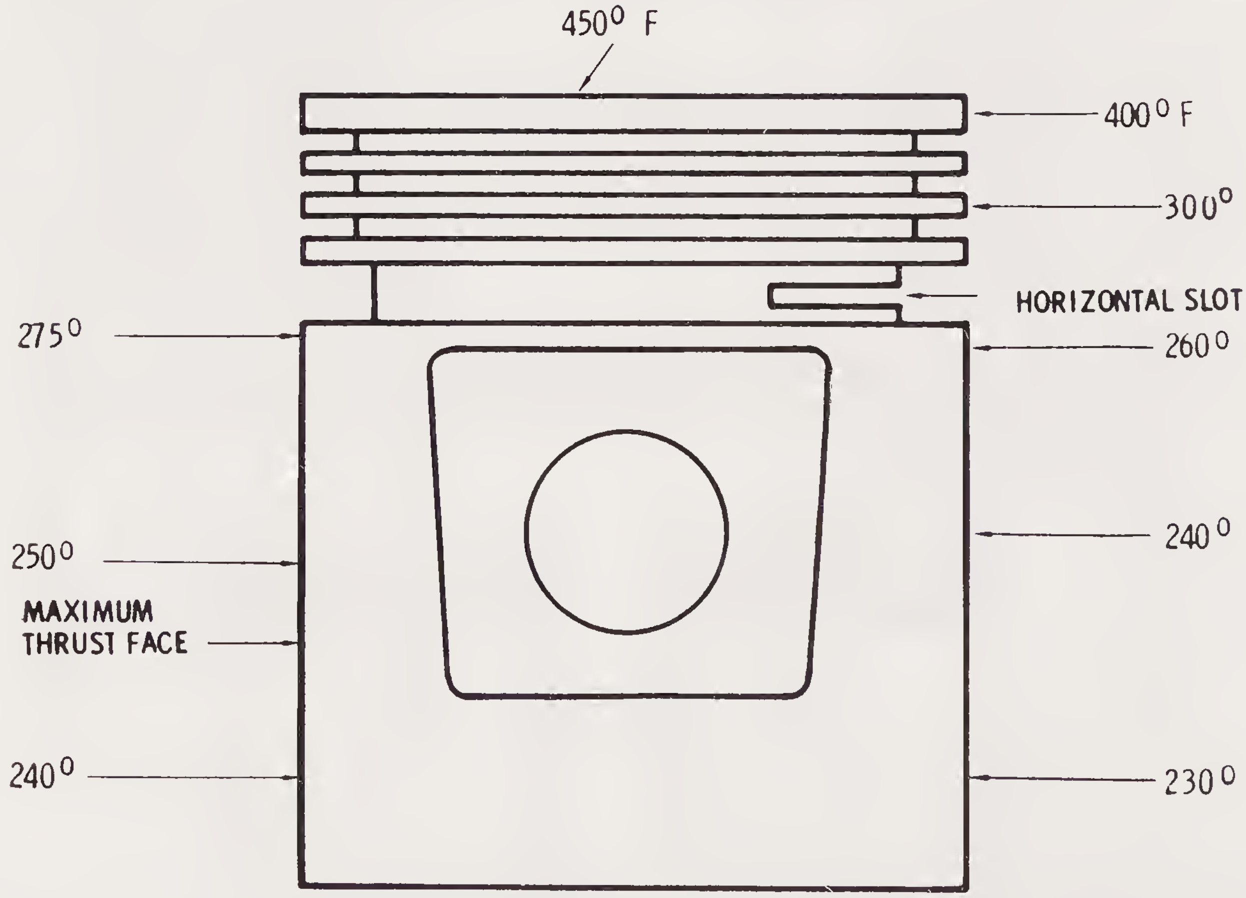



**Fig. 4-7. Typical working temperatures of different parts of a piston.**

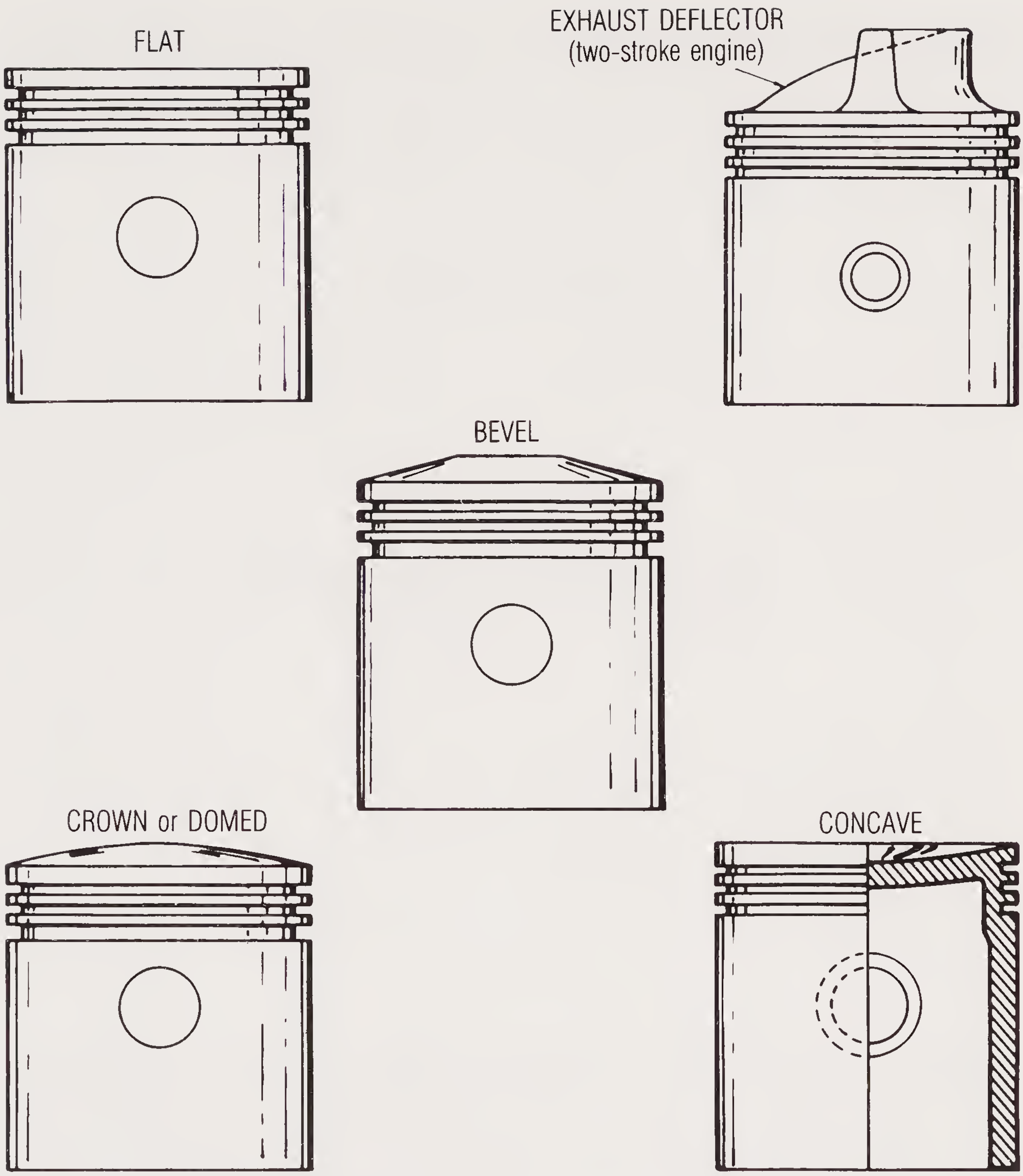



**Fig. 4-8. Various shapes of pistons.**

It must be understood that in any particular engine the temperatures of the piston are always varying, depending upon many running conditions, such as load (amount of throttle opening) speed, efficiency of the circulating water, ambient temperature, etc.

## PISTON CLEARANCES

Piston clearances depend on the design of the piston and the temperature at which it is expected to operate. It will vary from less

than one-thousandth of an inch in low-speed, water-cooled engines to as high as ten-thousandths of an inch in air-cooled, high-speed competition engines. Piston manufacturers' specifications should always be utilized when checking or fitting pistons.

CHAPTER 5

# Piston Rings

The function of piston rings is to provide a seal between the piston and cylinder, permitting the gases to be compressed in the cylinder. The piston rings, therefore, must contact the cylinder walls evenly and should fit snugly in the ring grooves to prevent the compressed gases from escaping past the rings.

In the gas engine, the piston ring appears to be a very simple thing, but due to the exacting requirement of its use, it has taken years of experience, research and testing to develop the successful technique of manufacture.

Piston rings have been designed in a great number of variations to serve present-day requirements, whereas originally there were only simple split rings made of cast iron. See Fig. 5-1.

Modern piston rings are made of steel as well as cast iron and are often made in multiple sections instead of in a single piece. Their designs are often quite complicated. They are heat treated in

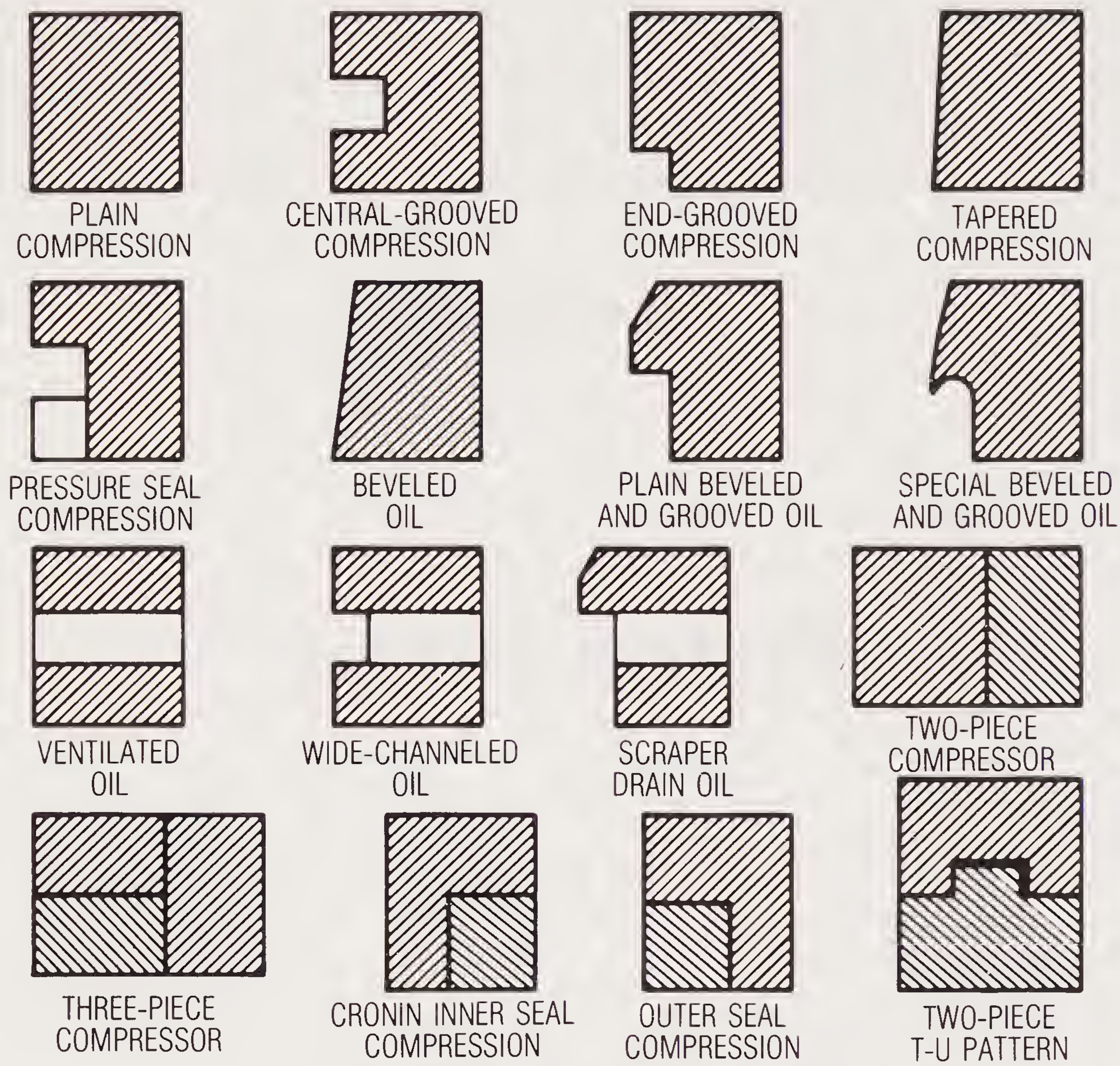



**Fig. 5-1. Various piston ring cross sections.**

various ways and plated with other metals. They are, furthermore, made in two distinct classifications, namely:

1. Compression rings.
2. Oil control rings.

## COMPRESSION RINGS

Perhaps no part of a gas engine mechanism has received more attention with respect to preventing leakage of the compressed charge into the crankcase and leakage of oil into the combustion chamber than has been given to those piston rings whose function it is to control both compression and oil leakage.

The first function of rings is to prevent compression loss, that is, to prevent any loss of pressure of the compressed charge by

leakage or *blow-by*, as it is usually called. The protection against this is the compression rings. They are of two general types, namely:

1. Plain.
2. Grooved.

The plain ring is a single-function ring and the grooved ring a double-function ring. The plain compression ring is shown in Fig. 5-2, illustrating the various cuttings of the joint, as straight, angle and step joints. The joint to be used is determined principally by the proportions of the ring.

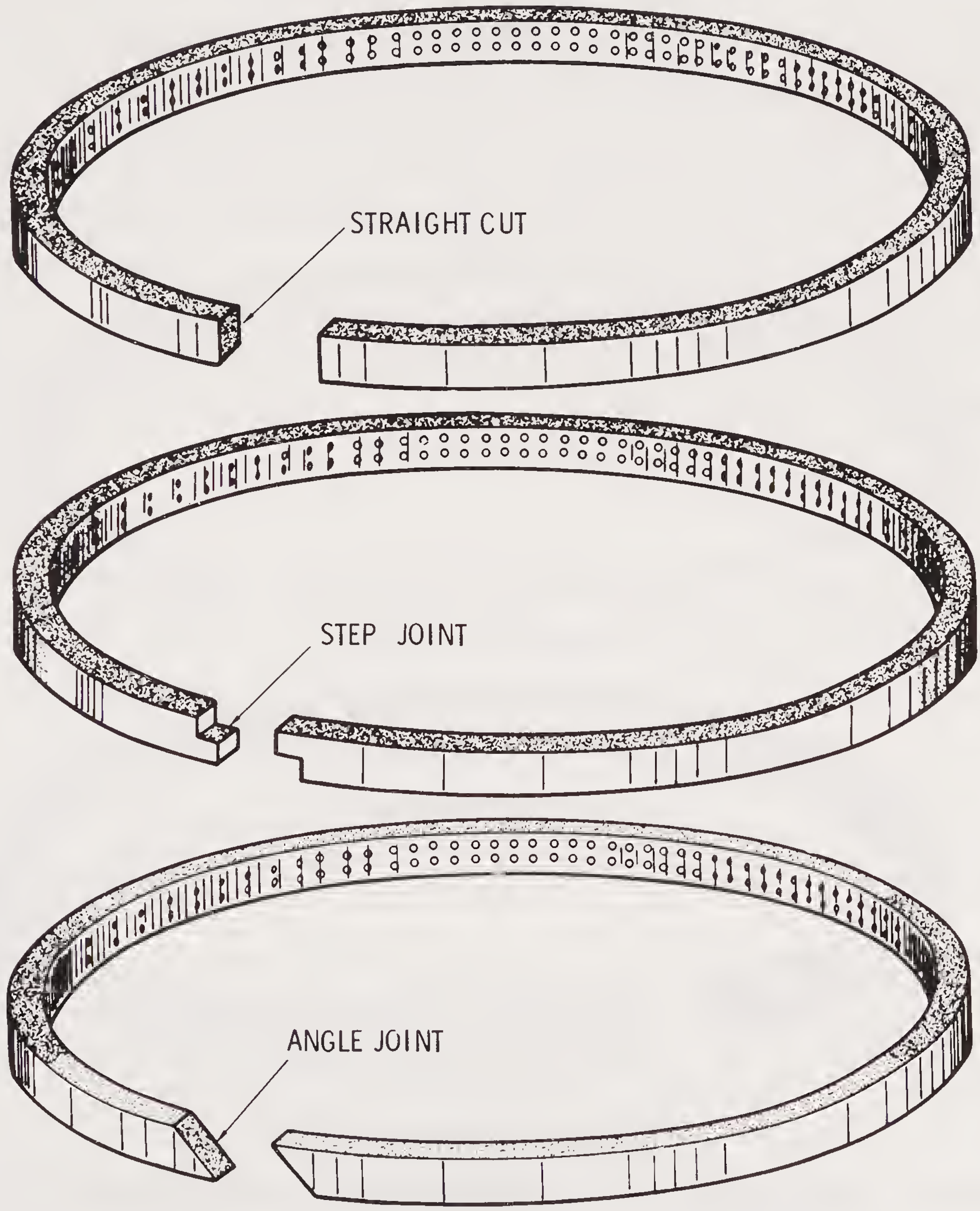



**Fig. 5-2. Plain compression rings.**

The straight joint is suitable for diameters up to 8 in.; the angle joint is for large diameters and the step joint is suitable for extremely narrow widths. The plain compression ring depends upon its ability to prevent loss of compression by its tight or precision fit all around its circumference.

An auxiliary to the plain compression ring is the grooved or oil seal ring. It is a good heat ring for the top piston groove; or preferably in the second groove in combination with the plain compression ring to seal compression, that is to say, as a final stop against compression leakage.

In construction, as shown in Fig. 5-3, a centralized groove on the face of the ring holds the proper amount of oil, maintaining an oil film between the ring and the cylinder wall. In operation, even if the groove should fill with carbon (which it naturally does), the ring continues to function as intended because the carbon is oil-saturated and cannot harden. This ring is sometimes called the scraper oil ring, but the author prefers to consider it as the grooved compression ring in order to differentiate more clearly between compression rings and oil control rings.

There are many types of compression rings in both the plain and grooved classes, such as:

1. Lower end grooved.
2. Tapered.
3. Step seal.
4. Pressure seal.

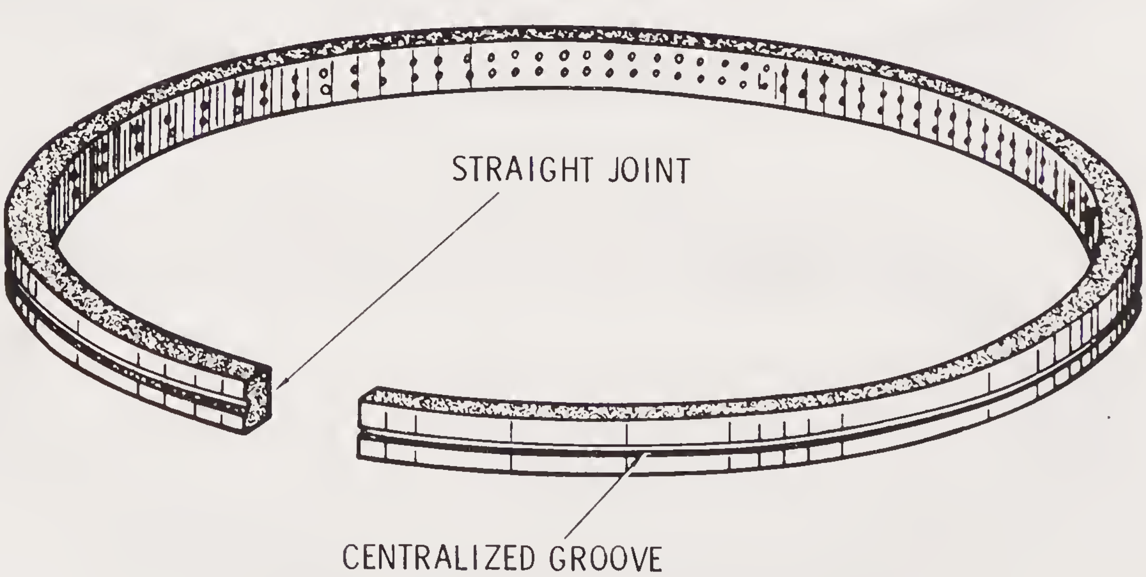



**Fig. 5-3. Centralized-grooved compression ring, sometimes called the oil seal compression ring.**

Fig. 5-4 shows an end-grooved compression ring. In construction it has a continuous groove around the lower outer edge. The object of this groove is to collect a small amount of oil, which helps lubrication and forms an added "hydraulic" seal to prevent the escape of the compressed gases from the combustion chamber. This type of ring is used chiefly as an oil-regulating compression ring and should be installed in the lower compression groove on automobile and diesel pistons.

The tapered compression ring, as shown in Fig. 5-5, differs from other plain compression rings in that it has a 2° taper on its outside or acting face.

This angle is so small that it cannot be discerned by the naked eye, and therefore the acting face, from which the taper starts outwardly and which should be turned toward the piston head, is stamped "UP" as an aid to correct installation. This ring is used mainly as an oil control compression ring to keep oil down while

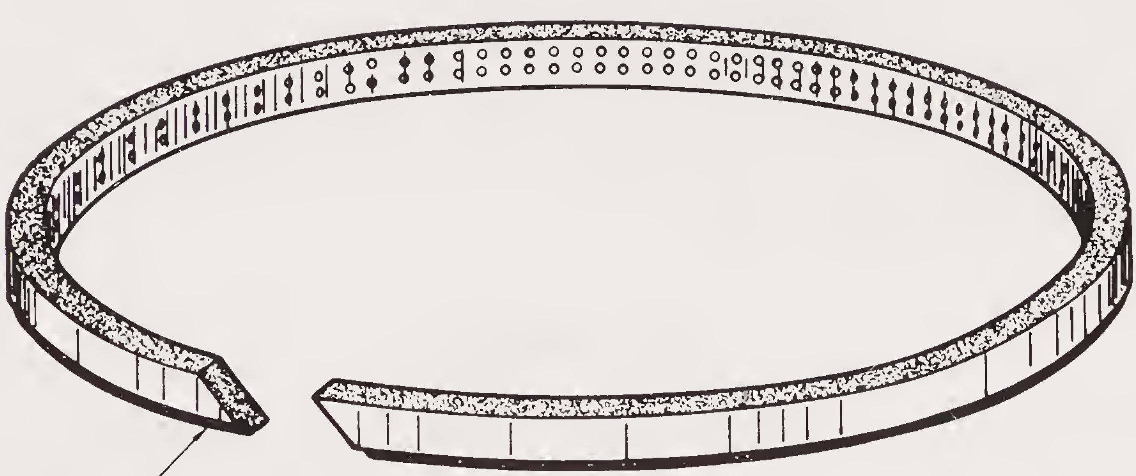



**Fig. 5-4. End-grooved compression ring.**

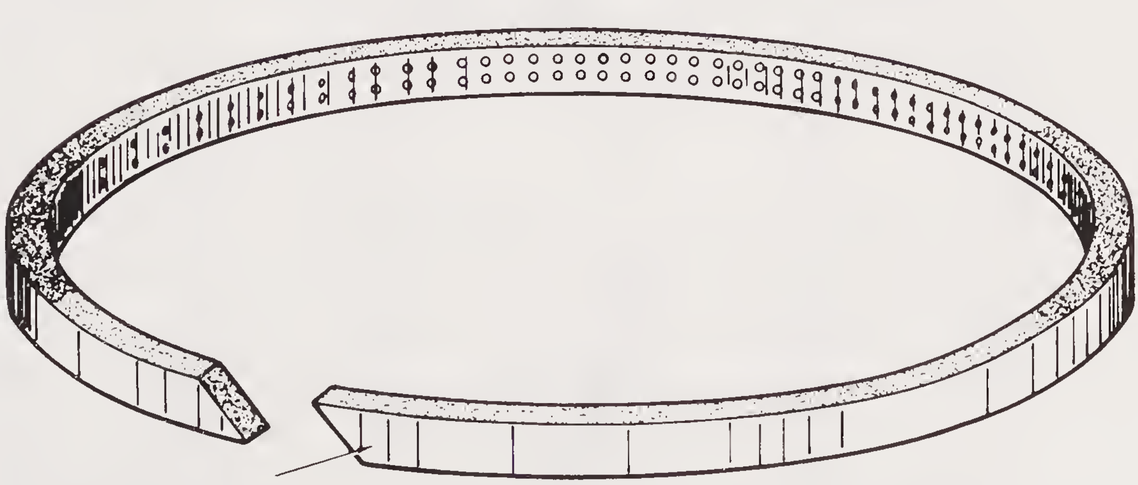



**Fig. 5-5. Tapered compression ring.**

the rings seal in. Most frequently it is used in aircraft engines to form an oil seal during the initial "run-in" period. It also has its use in elliptical or distorted cylinders.

The step seal ring, as shown in Fig. 5-6, is a one-piece hammered concentric ring. In construction, one leg of the joint is triangular in section and the other leg is pentagonal.

It is a good replacement ring in worn cylinders where the cylinder is noncircular and taper is present. This ring, when properly installed, combines the strength of the single-piece ring with the sealing qualities of the multipiece ring.

It is difficult to always classify rings as compression or oil control rings, as many are a combination of both classes, that is, double-function. For instance, what is called a pressure seal ring, as shown in Fig. 5-6, should be (according to the manufacturers) installed in the second groove from the head of the piston with a plain compression ring in the first groove. It acts as a fire check ring in the second groove and as oil rings in the lower grooves.

In gas, oil and diesel engines, the pressure seal ring is used to advantage to replace one or more of the compression rings; however, it is advisable to use plain compression rings in the first one or two grooves as fire check rings.

## OIL RINGS

The rapid increase in compression pressures and piston speeds has taxed the ingenuity of manufacturers of piston rings and has resulted

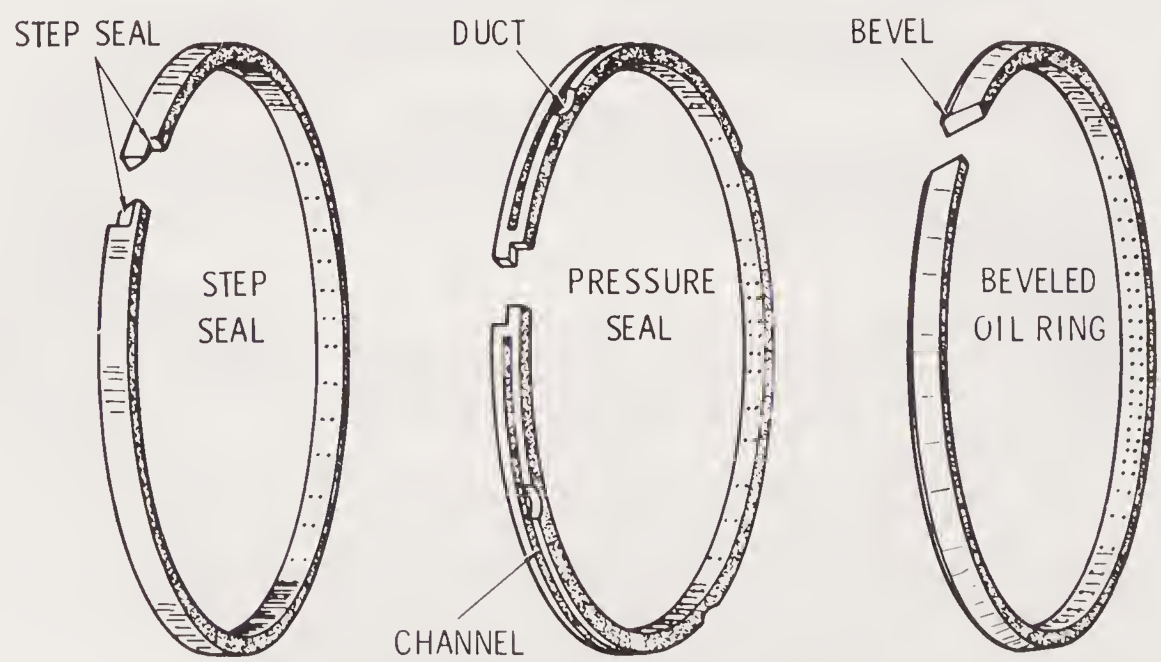



Fig. 5-6. Various types of piston rings.

in the introduction of a multiplicity of rings—both compression and oil types—due to research and experimentation on the part of the manufacturers. On account of this, piston rings are now available to meet the very severe conditions imposed on them.

With respect to oil control rings, numerous types have been developed as listed in the classification. Fig. 5-6 shows a beveled-type oil ring. This is a one-piece hammered ring having the upper part of the circumferential surface beveled and presenting only a narrow active face or bearing surface to the cylinder walls. In operation on the upstroke, this ring rides over the oil and presses it to a thin film on the cylinder walls. On the downstroke, the ring scrapes the excess oil back toward the crankcase.

In installation, the beveled ring should be installed in the groove farthest from the head of the piston, with the beveled side up or toward the piston head. On a piston containing one or more grooves suitably relieved for oil drainage, the beveled oil ring should be installed in the groove or grooves so relieved.

Oil drainage can be provided in several ways. One method is to undercut the skirt of the piston below the oil ring groove, allowing sufficient clearance for the oil to drain back to the crankcase.

Another method is to machine an oil-collecting groove on the piston around the lower, outer edge of the oil ring groove and to drill a series of holes at an angle through the piston wall from this oil-collecting groove. This type of oil ring is used largely in two-cycle engines and in aeronautical engines. It can be used wherever a scraping ring is required.

Fig. 5-7 shows a plain beveled and grooved oil ring. The groove is rectangular and the bevel is not as pronounced as the special beveled type. The scraping edge of the groove in this ring always remains exactly in the center of the ring. In installations subject to much wear, this ring is recommended instead of the special beveled and grooved oil ring.

A special beveled and grooved oil ring is shown in Fig. 5-7. *In construction*, it is a one-piece hammered ring with the upper edge gradually tapering to a narrow cylinder contacting surface, which forms a scraping edge for an undercut corner groove opening downward and outward.

*In operation*, the ring rides over the oil with the least possible scraping action on the upstroke of the piston and scrapes the oil

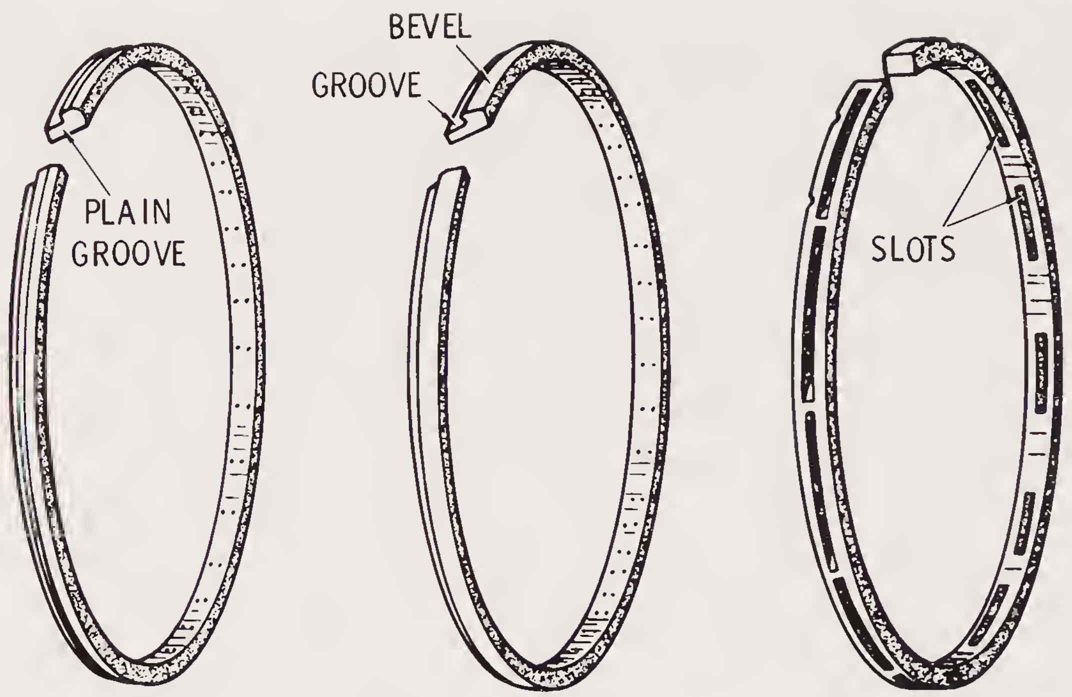



**Fig. 5-7. Oil rings.**

into the groove in the ring on the downstroke of the piston. On the next upstroke of the piston, oil that is trapped in the groove is again delivered to the cylinder walls for lubrication.

Some form of oil relief should be provided on the piston in order to drain the excess oil back to the crankcase. This oil relief may be in the form of holes drilled at an angle through the piston groove or, in case the ring groove is near the bottom of the skirt of the piston, the diameter of the skirt below the ring groove may be reduced so as to permit the free drainage of the oil past this section of the piston.

This ring should be installed in the groove farthest from the head of the piston, with the beveled side up or toward the piston head. If one or more grooves on the piston are suitably relieved for this oil ring, then install in grooves so relieved. This type of ring is used in engines and air compressors, particularly in the larger sizes.

On rings for horizontal machines, the cylinder contacting surface of each ring is broader than on rings for vertical machines. Fig. 5-7 shows a ventilated oil ring. *In construction*, it is a one-piece hammered ring having elongated slots passing through the body of the ring, with cylinder contacting lands between all slots. The slots are closely spaced and of ample width to ensure maximum drainage. The narrow lands between the slots represent solid wear-resistant bearing surfaces which ensure long life to the rings.

*In operation*, when the ring moves rapidly over the surface of

the cylinder, considerable oil pressure is built up ahead of the ring. This pressure builds up to such an extent that oil passes the cylinder-contacting face of the ring. The pressure is then suddenly relieved as the slot moves over the oil so that the surface tension of the oil causes a wave of oil to rise up into the slots. The greater portion of this wave is then cut off by the following edge of the ring. Thus, excessive oil is removed from the cylinder by a method similar to that used in an ordinary vacuum cleaner.

In application, the ventilated oil ring is used extensively in normal or high-speed vertical engines of all designs and should be installed in the piston groove farthest from the head of the piston. It is frequently advantageous to install two ventilated oil rings in the two lowest grooves when the piston contains a total of four or more grooves.

The wide-channeled oil ring, as shown in Fig. 5-8, is a one-piece hammered piston ring having a series of extra-wide slots opening into two channels. One of these channels passes across the point and extends for a distance of 90° on each side of the joint. The other channel extends for approximately 180° around the ring on the side opposite the joint. The two channels are separated from each other by narrow dams. *In operation*, it removes the excess oil from the cylinder wall by a method similar in principle to that employed in a vacuum cleaner.

The wide-channeled ring has a smaller bearing surface and accordingly exerts a higher unit pressure than the ventilated-type ring, thus rendering it more effective as an oil control ring. *In operation*, by having two separate channels in the ring in place of one continuous channel, oil that is collected in these two channels must drain back through the ring instead of flowing around the ring and collecting in one place. Thus, not only is ample drainage taken care of by preventing too great an accumulation of oil in one spot, but lubrication is also improved because of a better distribution of oil.

The excess oil is drained off from the channels through the slots to the rear of the ring and thence to the interior of the piston through oil relief holes. These holes should be drilled in the back of the piston groove, perpendicular to the axis of the piston, and they should be as large and numerous as the strength of the piston will permit. This ring is suitable for vertical high-speed engines and

compressors. It should be installed in the groove farthest from the piston head.

Fig. 5-8 shows a scraper drain oil ring. *In construction,* it is a one-piece hammered ring having the upper, outer edge beveled and a corner groove formed on the lower, outer edge with oil passages extending from the upper corner of the groove to the back of the ring.

*In operation,* the ring rides over the oil on the cylinder wall on the upstroke of the piston and scrapes oil into the groove in the ring on the downstroke of the piston. The oil thus collected passes straight through the oil passages in the ring and then through holes in the piston.

It is essential to have oil relief holes in the piston in the back of the groove in which the scraper drain oil ring is to be used. The greater the drainage area in the piston grooves, the greater the amount of oil that will be removed. This ring is suitable for the groove farthest from the head of the piston, unless the piston contains four or more ring grooves with one on the skirt. Then it is advisable to install two rings of this type, one in the groove on the skirt and one in the groove just above the piston pin.

## MISCELLANEOUS RINGS

In addition to the rings already described, there are numerous other types having features designed to meet some special conditions. Fig. 5-8 shows a contracting ring. *In construction,* this ring is hammered on its outer circumference so that it will contract and bear on its inner circumference. It can be beveled so as to act as a wiper ring which will ride over the oil on one stroke of the piston and scrape oil on the reverse stroke.

The contracting ring is designed primarily for installation in a specially constructed groove in the cylinder, so as to wipe oil from the skirt of a long trunk piston in a manner similar to that in which the beveled oil ring, when installed on the piston, removes excess oil from the cylinder.

A two-piece compressor ring designed to prevent undue cylinder wall pressure is shown in Fig. 5-9. The inner ring provides the necessary tension and effectually seals the joint of the outer ring. When subjected to high pressure that may build up behind

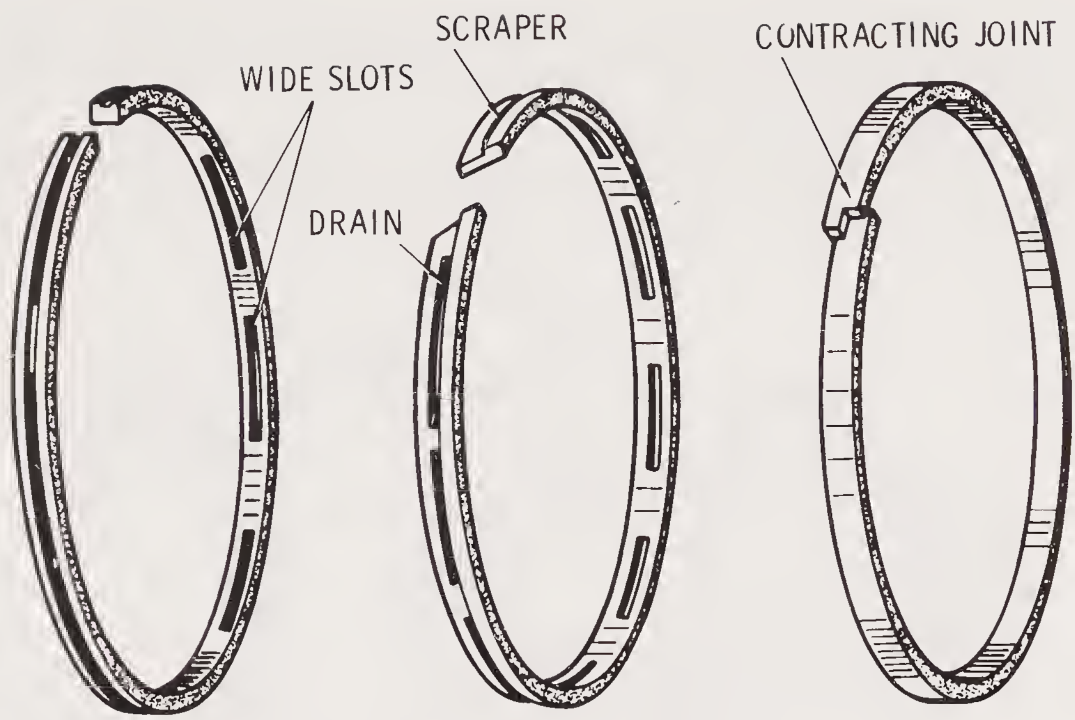



Fig. 5-8. Wide-channel piston rings.

the ring, causing the ring to expand, there is a definite restraining action obtained due to friction between the cooperating surfaces of the two rings, which prevents undue cylinder wall pressure.

A three-piece compressor ring is shown in Fig. 5-9. Two types of ring, known as inner seal and outer seal, that are especially

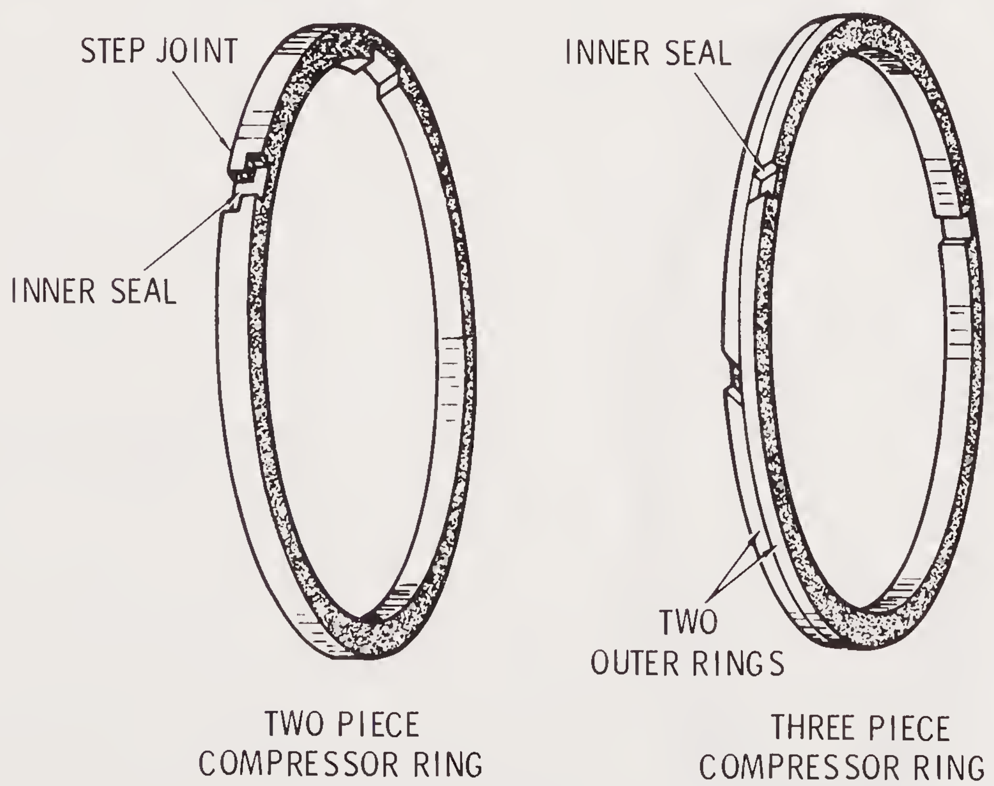



Fig. 5-9. Two- and three-piece compression rings.

suitable for diesel engines are shown in Fig. 5-10. These are special compression rings intended to be effective in preventing leakage in both new and worn cylinders.

Another ring well adapted to diesel engines is shown in Fig. 5-11. It is a double ring known as the T-U ring because of the cross-

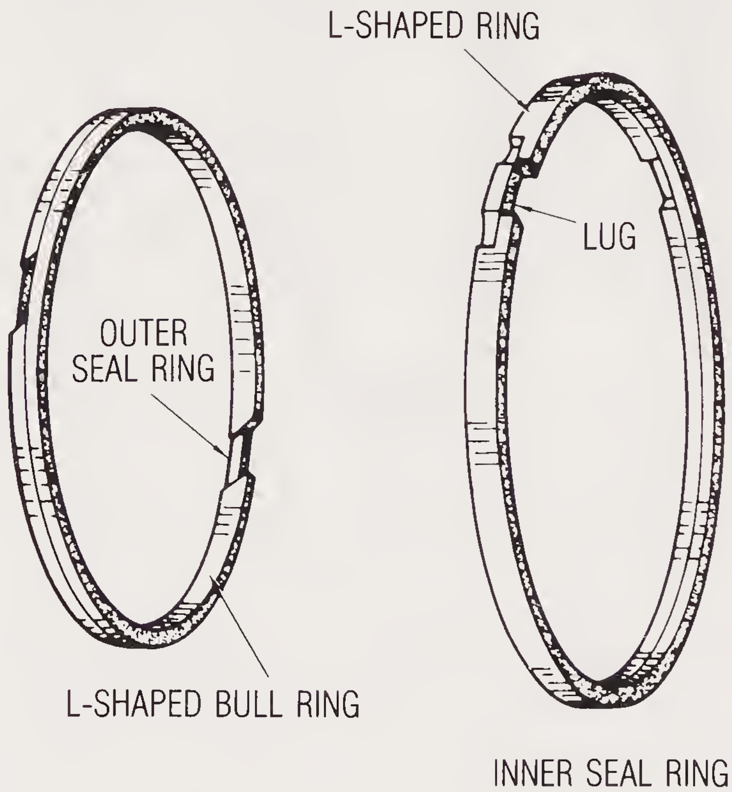



**Fig. 5-10. Inner and outer seal rings.**

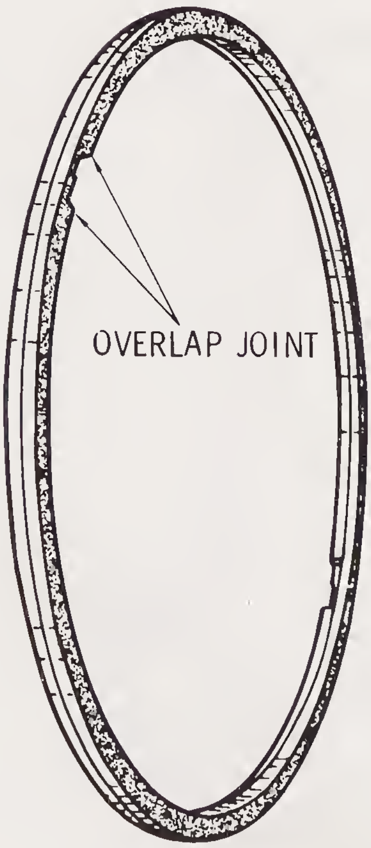



**Fig. 5-11. T-U ring.**

sectional shape of the two component rings. Each ring contains an overlapping joint intended to prevent leakage to the rear of the groove and, when assembled, to give efficient joint and groove seal.

The function of the segmental-type rings (Fig. 5-12) is to avoid

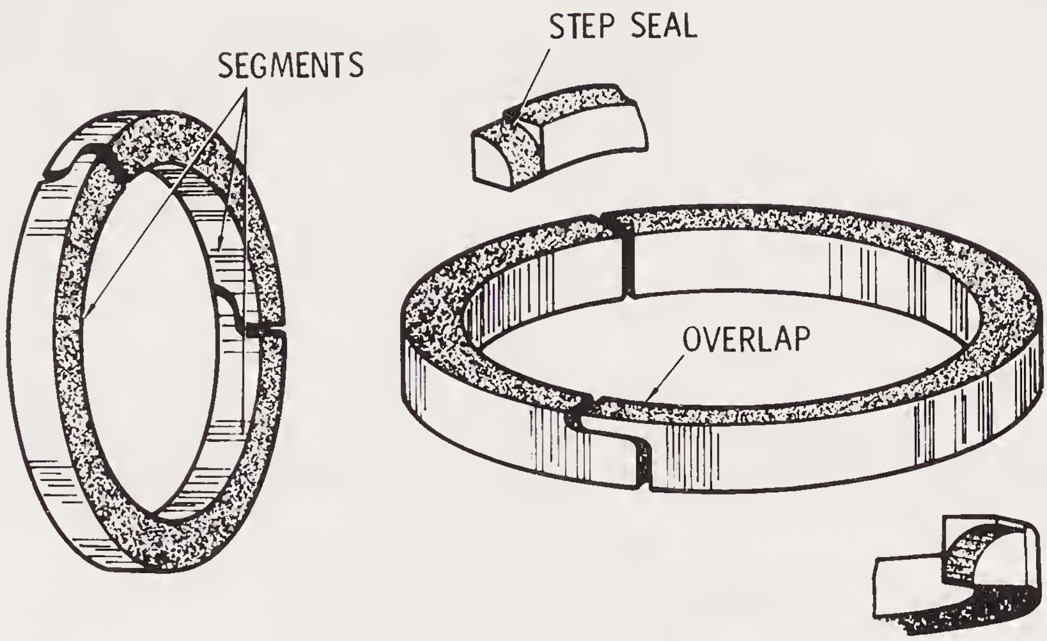



**Fig. 5-12. Segmental rings.**

the necessity of springing the rings when inserting them in the grooves. This is important in the case of thick, heavy rings. They are usually made in three interlocking segments as shown and when assembled in the groove form a continuous tight-sealing ring.

CHAPTER 6

# Connecting Rods and Wrist Pins

Piston pins, also known as *wrist pins*, serve as a connection between the upper end of the connecting rod and the piston. Piston pins are made of alloy steel with a precision finish and are case-hardened and sometimes chromium-plated to increase their wearing qualities. They form a pivot connecting one end of the connecting rod to the piston, which permits the lateral oscillating motion of the rod with reciprocating motion of the piston.

There are three methods of fastening a piston pin to the piston and connecting rod:

1. An *anchored* or *fixed* pin is attached to the piston by a set-screw running through one of the bosses; the connecting rod oscillating on the pin is shown in Fig. 6-1.
2. A *semifloating* pin is anchored to the connecting rod and turns in the piston pin bosses (Figs. 6-1 and 6-2).

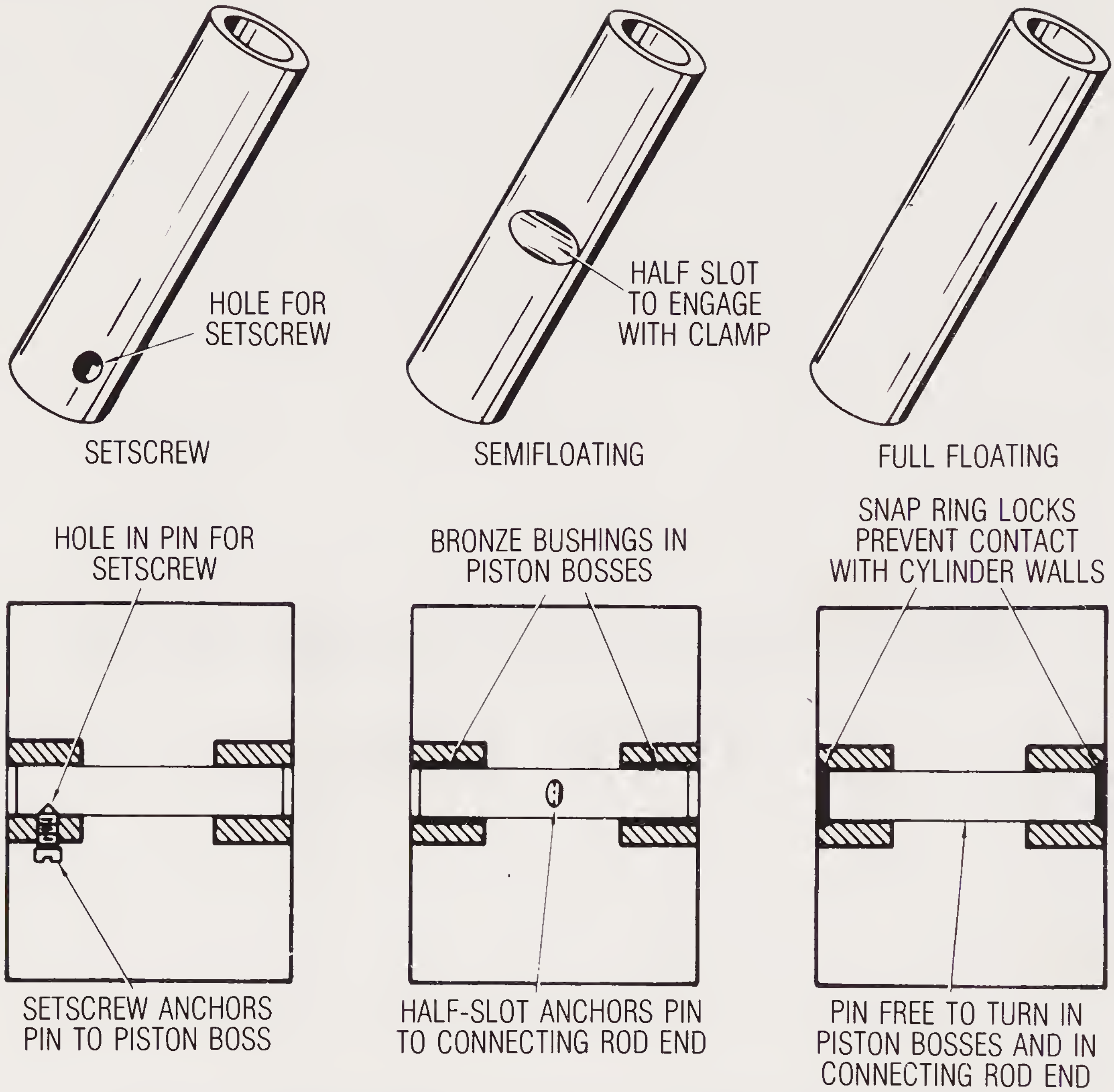



**Fig. 6-1. Three methods of connecting wrist pins to pistons.**

3. A *full-floating* pin is free to rotate in the connecting rod and in the bosses, but is prevented from working out against the sides of the cylinder by plugs or snap-ring locks (Fig. 6-1).

As will be noted, piston pins are of tubular construction, which gives them a maximum of strength with a minimum of weight. They are lubricated by splash from the crankcase or by pressure through passages bored in the connecting rods.

The *full-floating* pin is not anchored to either the piston or connecting rod and is free to turn in the connecting rod end or in the piston bosses. It is a plain pin and is sometimes called by that name. Since the full-floating pin is free to rotate or move sidewise, some form of locking device is necessary to prevent the pin from

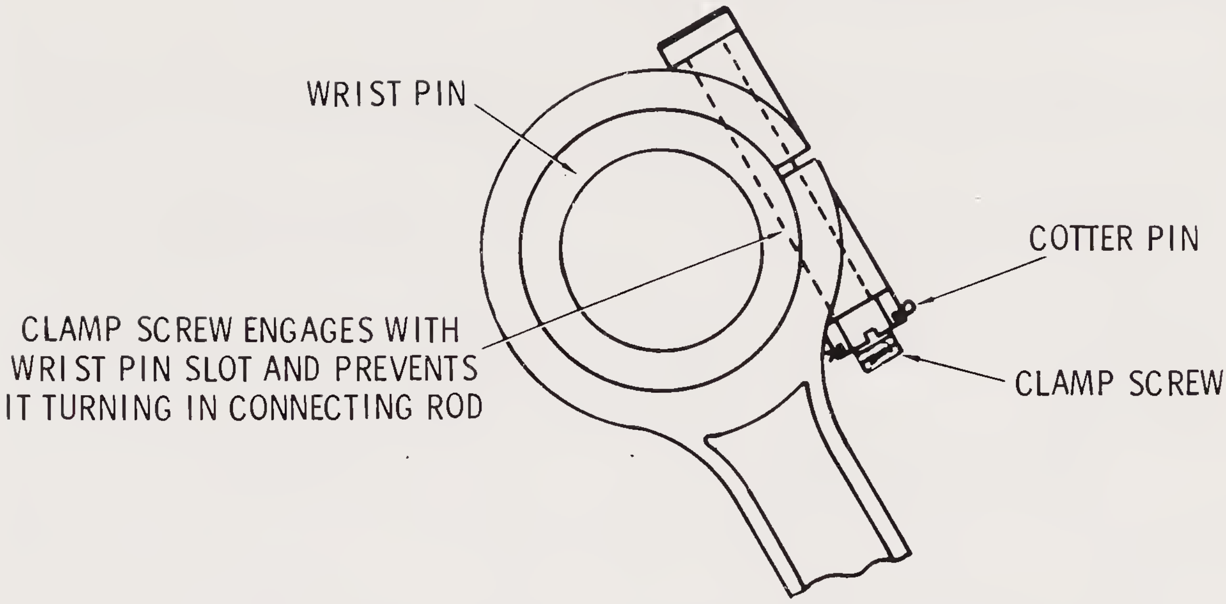



**Fig. 6-2. Semifloating wrist pin connection (clamp type).**

working to one side and rubbing against the cylinder walls, thereby damaging the walls. Numerous devices are used. A typical one consists of a snap ring fitted into recesses cut in the bosses at the ends. Fig. 6-3 illustrates numerous types of wrist pin construction.

*Semifloating* wrist pins are able to move in the piston only. The wrist pin must therefore be secured in the rod. This design has become the most popular since it does away with any rocking motion caused by the wrist pin moving in the narrow rod and also provides a means of keeping the wrist pin centered in the piston away from the cylinder wall. The most popular means of holding the wrist pin in the connecting rod is to machine the rod slightly smaller than the pin, creating a press fit. In heavy-duty engines, clamp-end rods are used (Fig. 6-2).

## CONNECTING RODS

The connecting rod is a connecting link between the piston and the crankshaft. It serves to transform the reciprocating motion of the piston into rotary motion at the crankshaft.

### Construction

Connecting rods must be light and yet strong enough to transmit the thrust of the piston. Automotive connecting rods are drop-forged from a steel alloy capable of withstanding heavy loads without de-

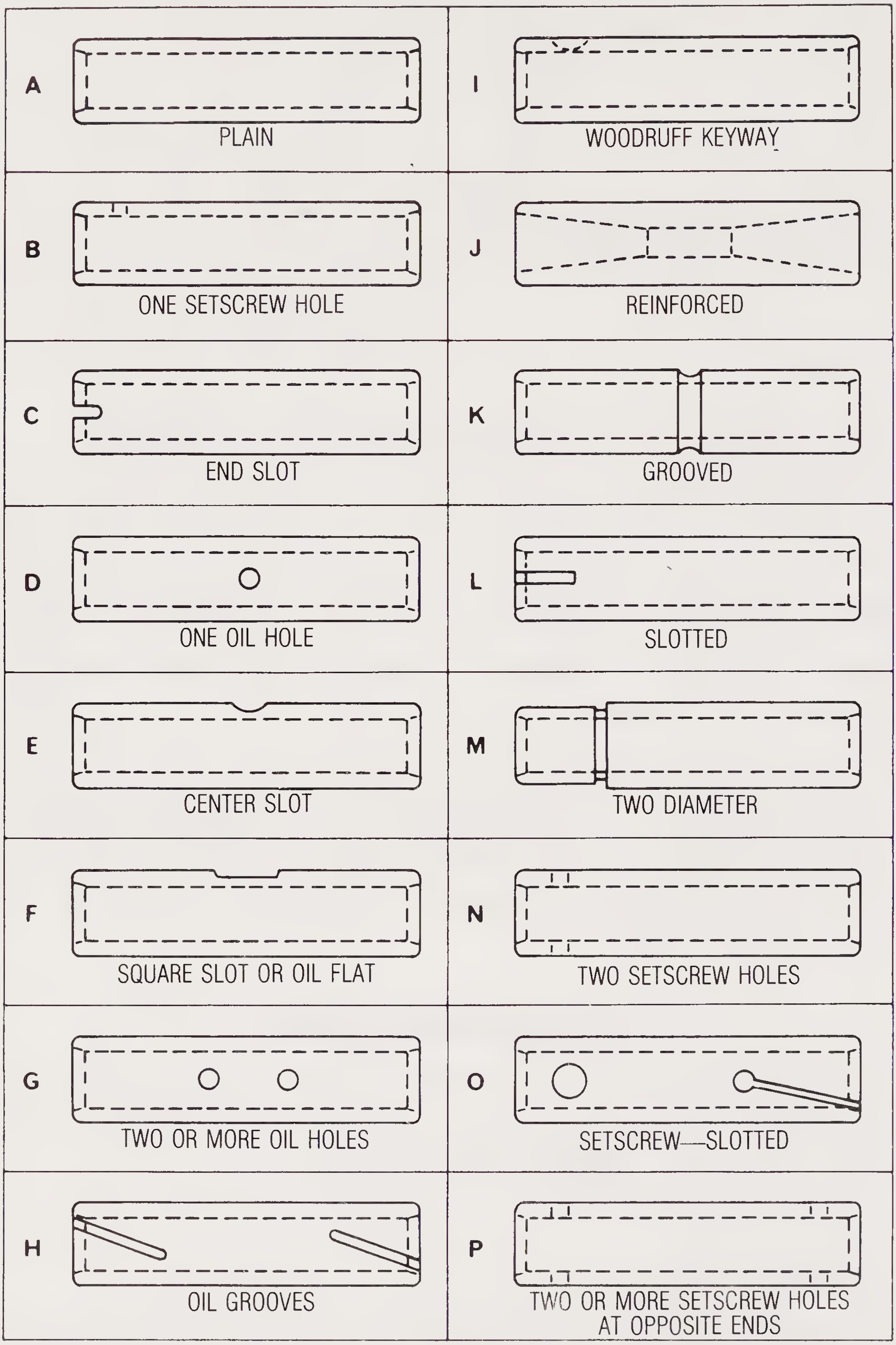



**Fig. 6-3. Various standard types of wrist pins.**

flection, that is, without bending or twisting. They are usually made in the form of an I-beam for lightness with maximum strength. Holes at the upper and lower ends are machined to permit accurate fitting of bearings. It is very important that these holes be parallel.

The upper end of the connecting rod is connected to the piston by the piston pin. If the piston is locked in the piston pin bosses or if it floats in both piston and connecting rod, the upper hole of the connecting rod will have a solid bearing or bushing of bronze or similar material. As the lower end of the connecting rod revolves with the crankshaft, the upper end is forced to rotate on the piston pin. Although this movement is not great, the bushing is necessary because the temperature and unit pressures exerted are high. If the piston pin is semifloating, that is, anchored to the connecting rod, a bushing is not required. See Fig. 6-4.

The lower hole of the connecting rod is split to permit it to be clamped around the crankshaft. The bottom part, or cap, is made of the same material as the rod and is attached by two or more connecting rod bolts. The surface that bears on the crankshaft is generally a bearing material in the form of a separate split shell, although in older engines the bearing material was spun or die-cast in the inside of the rod during manufacture.

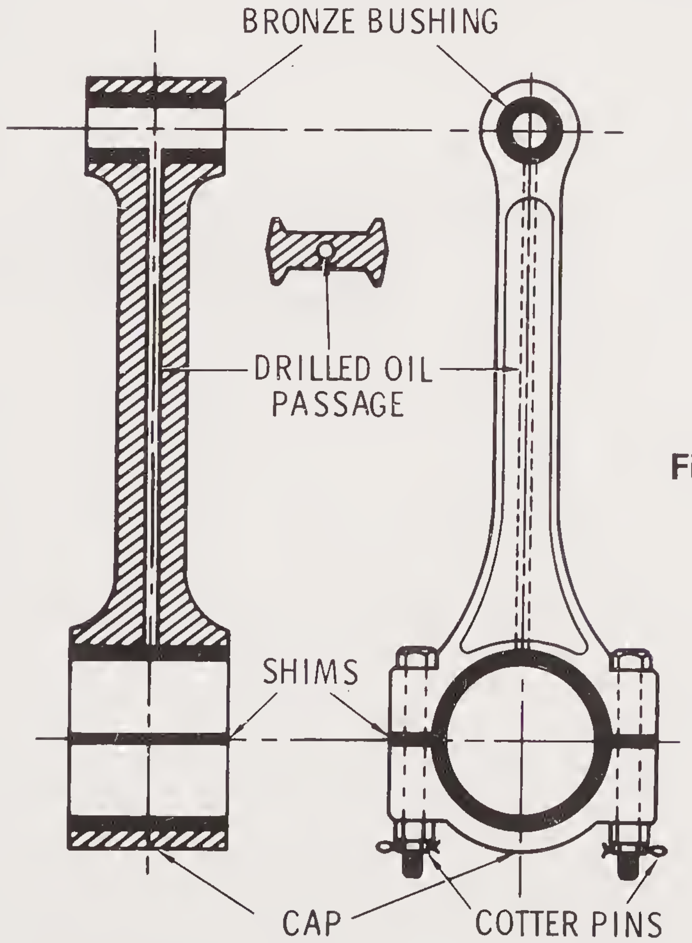



**Fig. 6-4. Heavy-duty connecting rod construction.**

The two parts of the separate bearing are positioned in the rod and cap by dowel pins, projections, or short brass screws. The shell may be all bronze or of babbit or aluminum-alloy metal face on a backing of bronze or steel. Roller-type bearings are sometimes employed, particularly on high-speed engines. Bearing inserts may be of the precision or semiprecision type.

The precision type is accurately finished to fit the crank pin and does not require further machining during installation. It is positioned by projections on the shell which match reliefs in the rod and cap. The projections prevent the bearings from moving sideways, but they permit rotary movement after the bearing cap is removed, thus making it possible to replace the bearing without

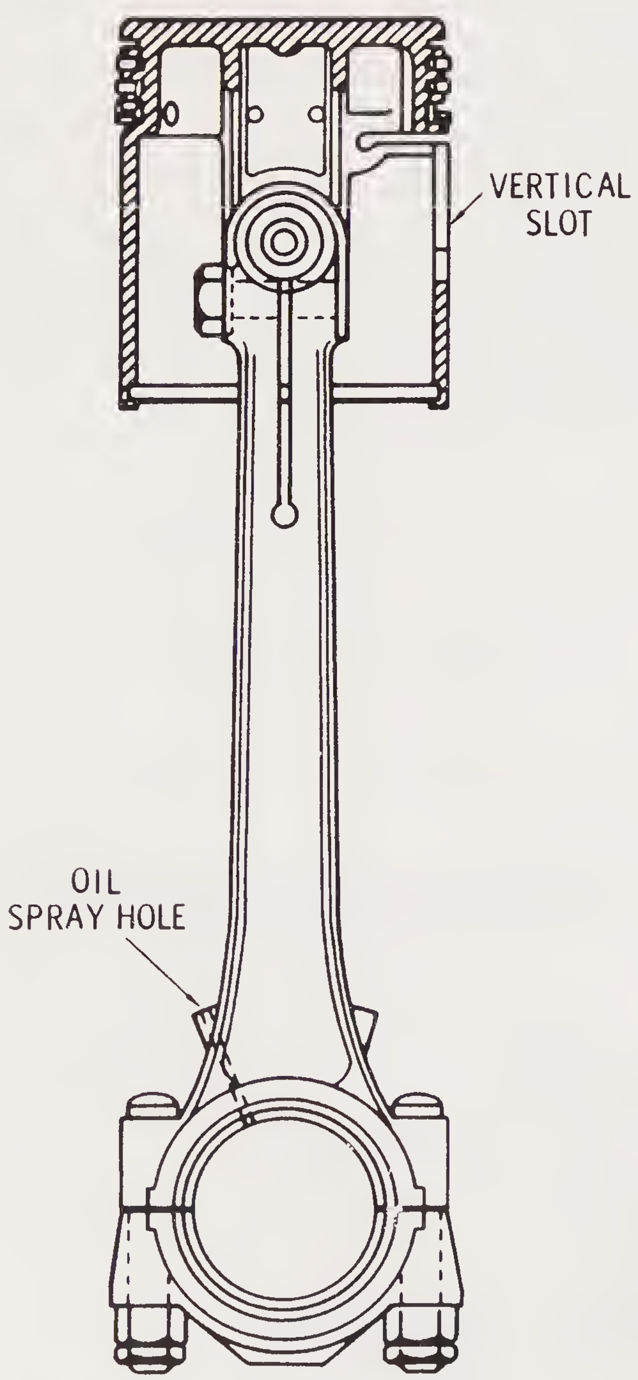



**Fig. 6-5. Typical heavy-duty piston and connecting rod assembly.**

removing the connecting rod from the engine. The semiprecision type is usually fastened securely to the rod and cap. Prior to installation, it is machined to the proper inside diameter to fit the cap and rod when bolted together. See Fig. 6-5.

## Aluminum-Alloy Connecting Rods

In an aluminum rod the sectional area is bigger than in steel rods, and the designer has an excellent opportunity to shape it for the best rigidity, having only the consideration of clearance between the edges of the cylinder wall and rod as the limiting factor against this design.

CHAPTER 7

# Crankshafts

The functions of a crankshaft are to convert the reciprocating motion of the piston and connecting rod into rotary motion and to transmit the resulting torque to the flywheel and clutch.

In its simplest form, it consists essentially of a shaft with one or more throws along its length, as noted in Fig. 7-1. The arrangement of the throws is determined by the desired firing order of the engine cylinders. The desired firing order is regulated by the relationship of the camshaft and crankshaft.

Crankshafts must be correctly proportioned to carry the great loads imposed upon them while turning at high speed and to resist the shocks due to the nature of the gas engine cycle.

## CONSTRUCTION

Crankshafts are generally made of forged steel or cast from an alloy of steel, nickel and iron. The rough casting or forging is then ma-

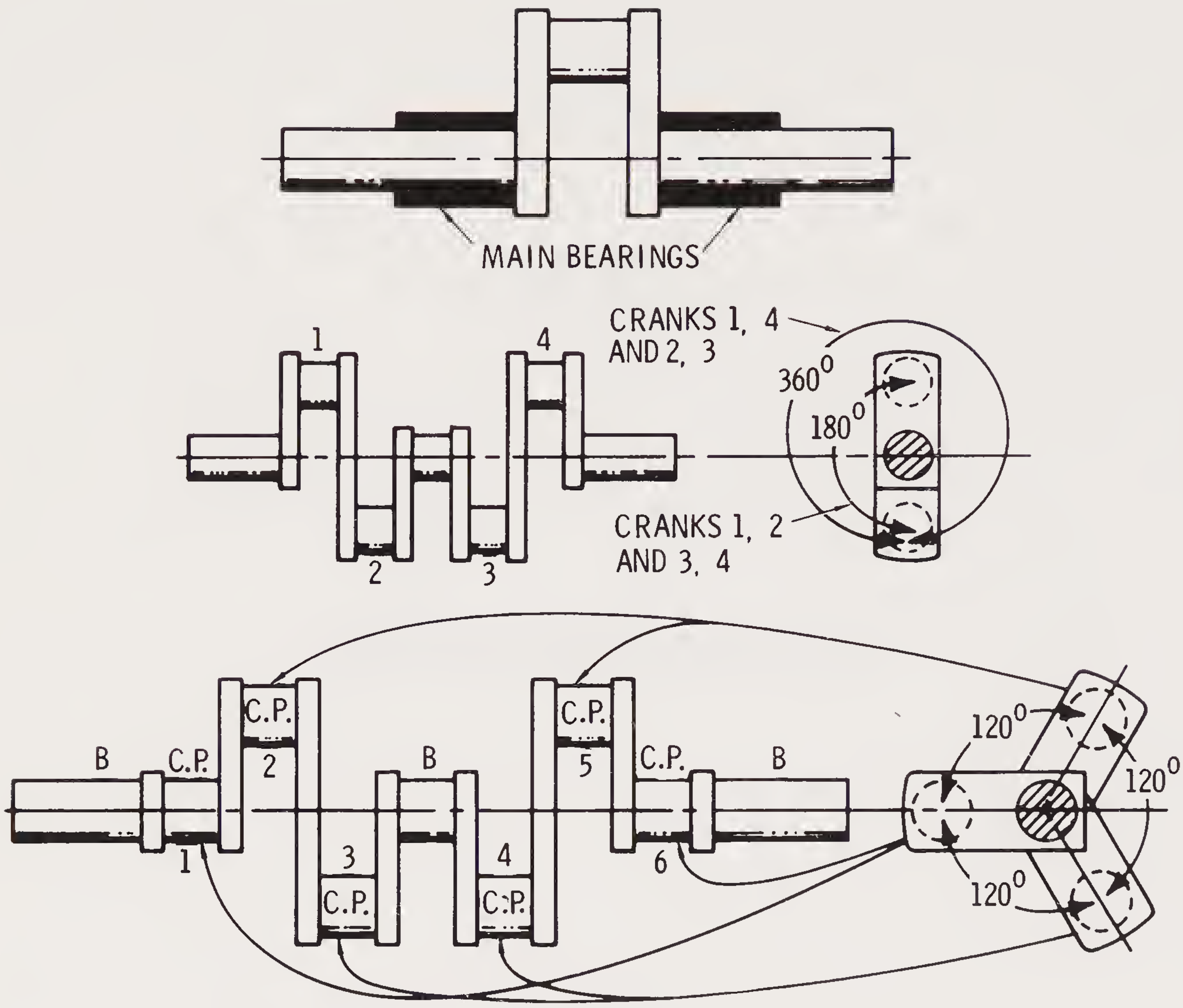



**Fig. 7-1. One-, four-, and six-throw crankshaft.**

chined to exact specifications. After machining many crankshafts are hardened. The nonbearing surfaces are plated with a light coating of copper. When the plating process is completed, the whole crankshaft is placed in a carburizing oven or an electroinduction furnace, where surfaces of the crankshaft not coated with copper become alloyed with the carbon, producing a thin, hard surface or bearing area.

This process is known as *case-hardening*. The crankshaft is completed by grinding the case-hardened surfaces.

## CRANKSHAFT BALANCE

Owing to the high rotative speed for which modern engines are designed, most manufacturers provide counterweights for the shaft. These are usually forged integrally with the crankshaft. See Fig. 7-2B.

The functions of a counterweight are:

1. To balance the weights of the piston, connecting rod, crank arms and crank pin, so that the assembly of moving parts will be in static equilibrium for all points of the stroke.
2. To provide an opposing centrifugal force to counteract the oppositely directed centrifugal force due to the connecting rod, crank arms and crank pin.
3. To counteract the inertia loads due to the moving parts during the accelerating and retarding portions of their travel and in this way avoid a considerable amount of vibration which would otherwise occur. Fig. 7-2A shows a shaft without counterweights.

The tendency of this arrangement is for the unbalanced weight of the piston, rod, crank arms and pin to move downward to the lower dead center. Fig. 7-2B shows the effect of a counterweight for static balance.

It must be evident that if enough metal is put into the counterweight so that its tendency to rotate to the bottom center is the same as that due to the weight of the piston, connecting rod, etc., the assembly will be in equilibrium for any crank position, that is, there will be no tendency to rotate, and the assembly will be in static equilibrium.

## CRANKSHAFT THROW ARRANGEMENT

While engine crankshafts are similar in design, the number of throws and their angular arrangement depend upon the number of cylinders to be operated and their firing order.

A single-cylinder engine will have one throw on the crankshaft as shown in Fig. 7-2B. A two-cylinder opposed engine with one cylinder on each side of the crankshaft (four-stroke cycle) will have two throws spaced 180° apart. An arrangement for alternate firing cylinders is shown in Fig. 7-3.

An identical crankshaft throw arrangement may be used for a two-stroke-cycle opposed engine having two cylinders firing at the same time.

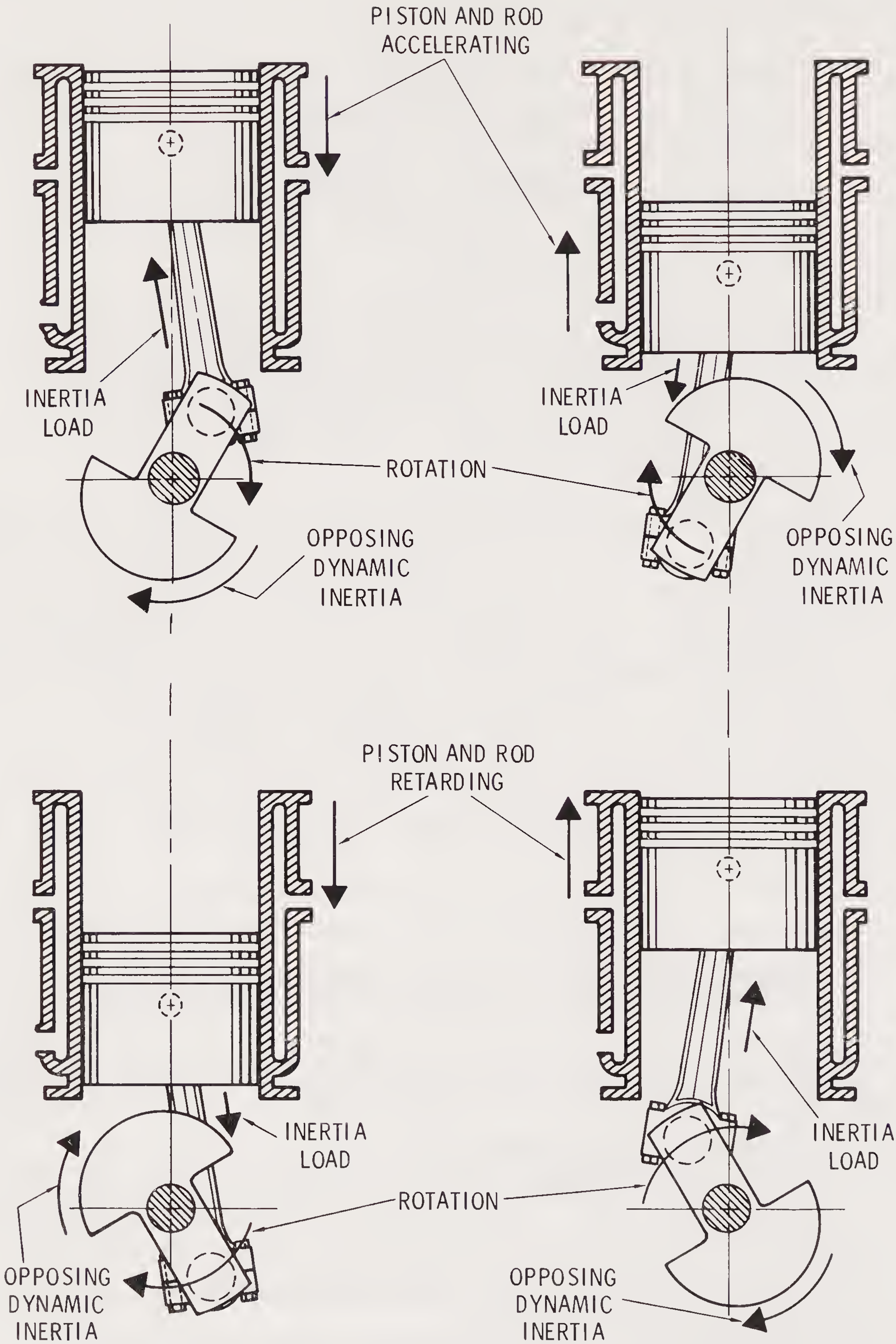



**Fig. 7-2A. Counterweights.**

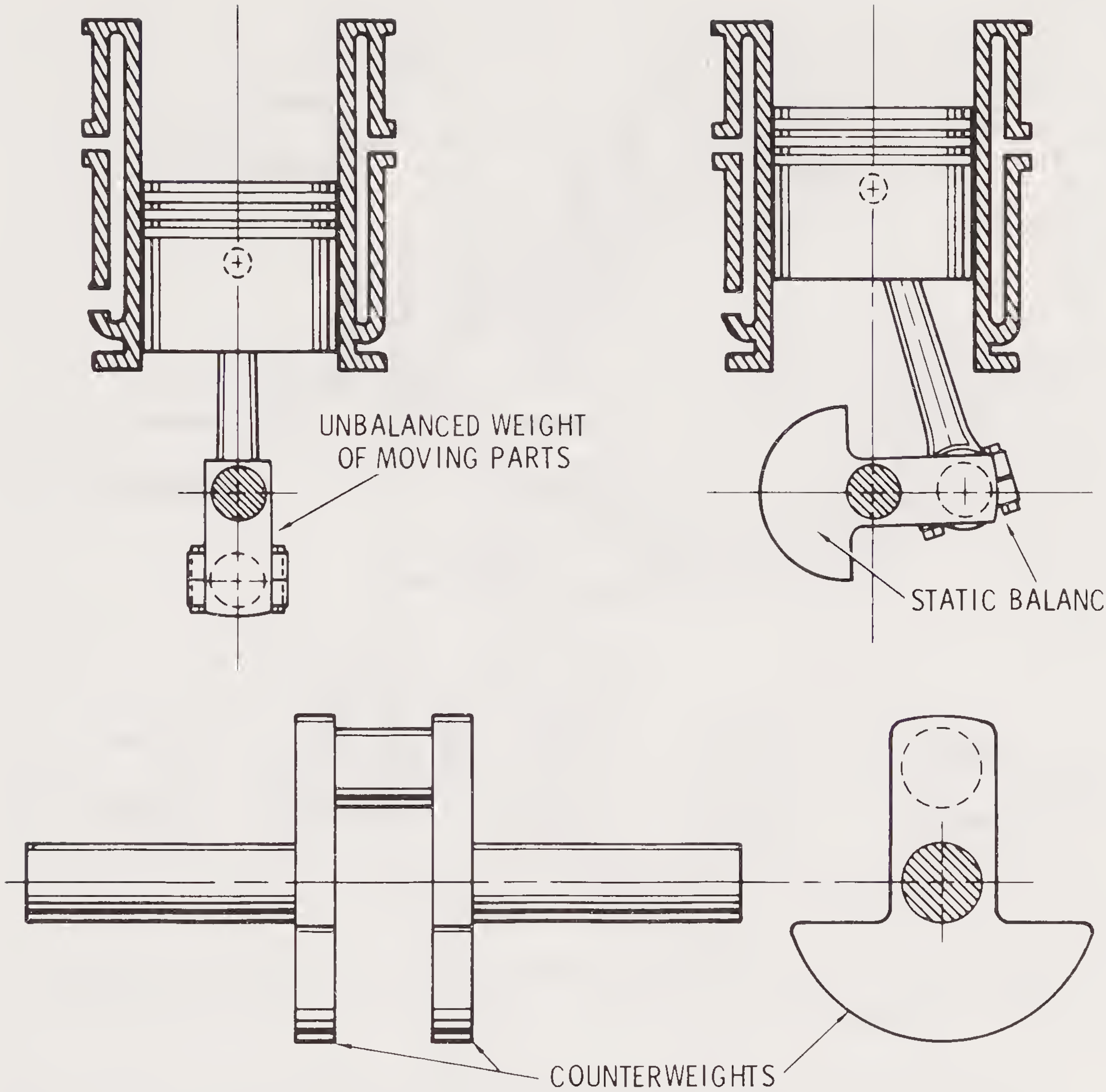



Fig. 7-2B. Crankshaft loading.

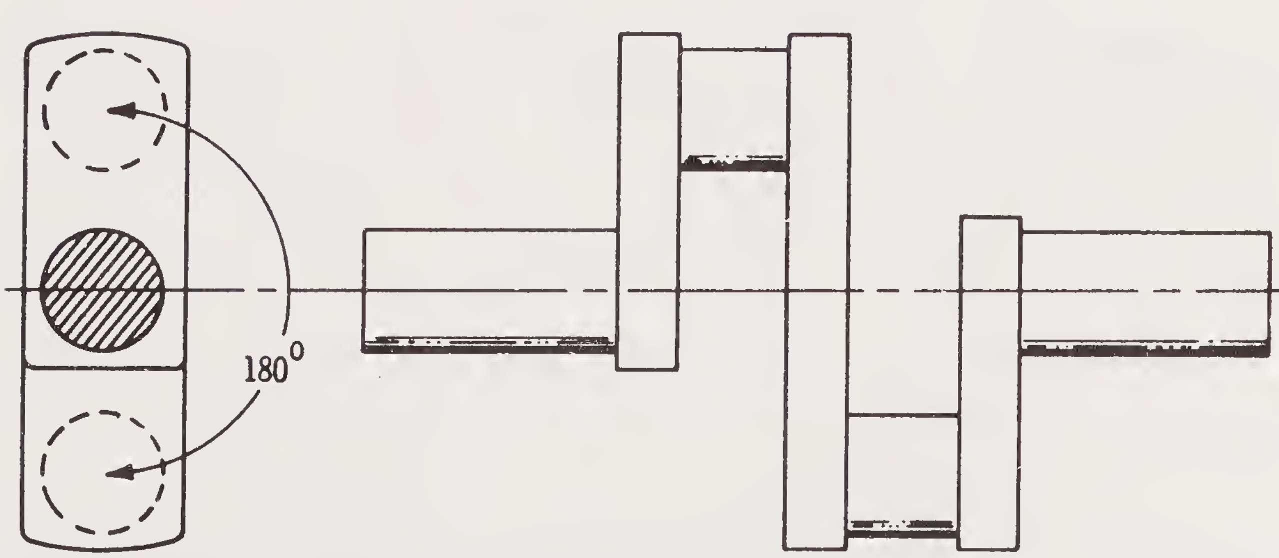



Fig. 7-3. A typical two-throw 180° crankshaft.

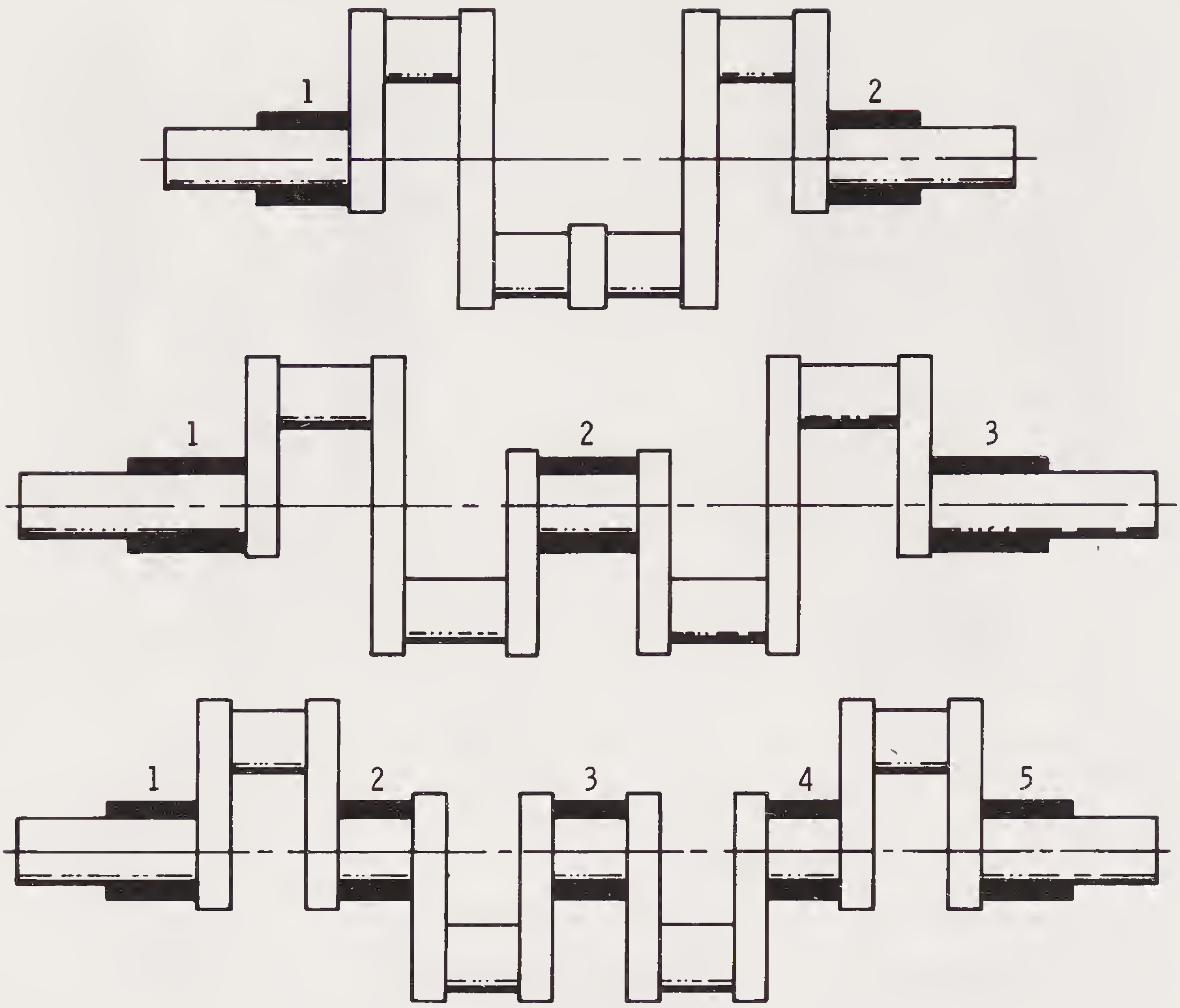



**Fig. 7-4. Four-throw crankshafts illustrating two, three and five main bearings.**

Crankshafts of four-cylinder engines, Fig. 7-4, have either three or five bearings. The four throws are in one plane, the throws for cylinders No. 2 and 3 being advanced 180° over cylinders No. 1 and 4.

Crankshafts for six-cylinder engines may have either three, four or seven bearings. The throws for the connecting rod bearings are forged in three planes 120° apart, with two throws in each plane. As noted in Fig. 7-1, throws No. 1 and 6 are in the first plane, throws No. 2 and 5 are in the second plane, and No. 3 and 4 in the third plane.

An eight-cylinder V-type engine may have two identical four-throw arrangements positioned end to end, with one set advanced 90° over the other. This is known as a 4-4 shaft, Fig. 7-5.

In the other design, known as a 2-4-2 shaft, Fig. 7-5, a set of four throws is positioned between two sets of two throws each. The end cylinders are advanced 90° over the center group.

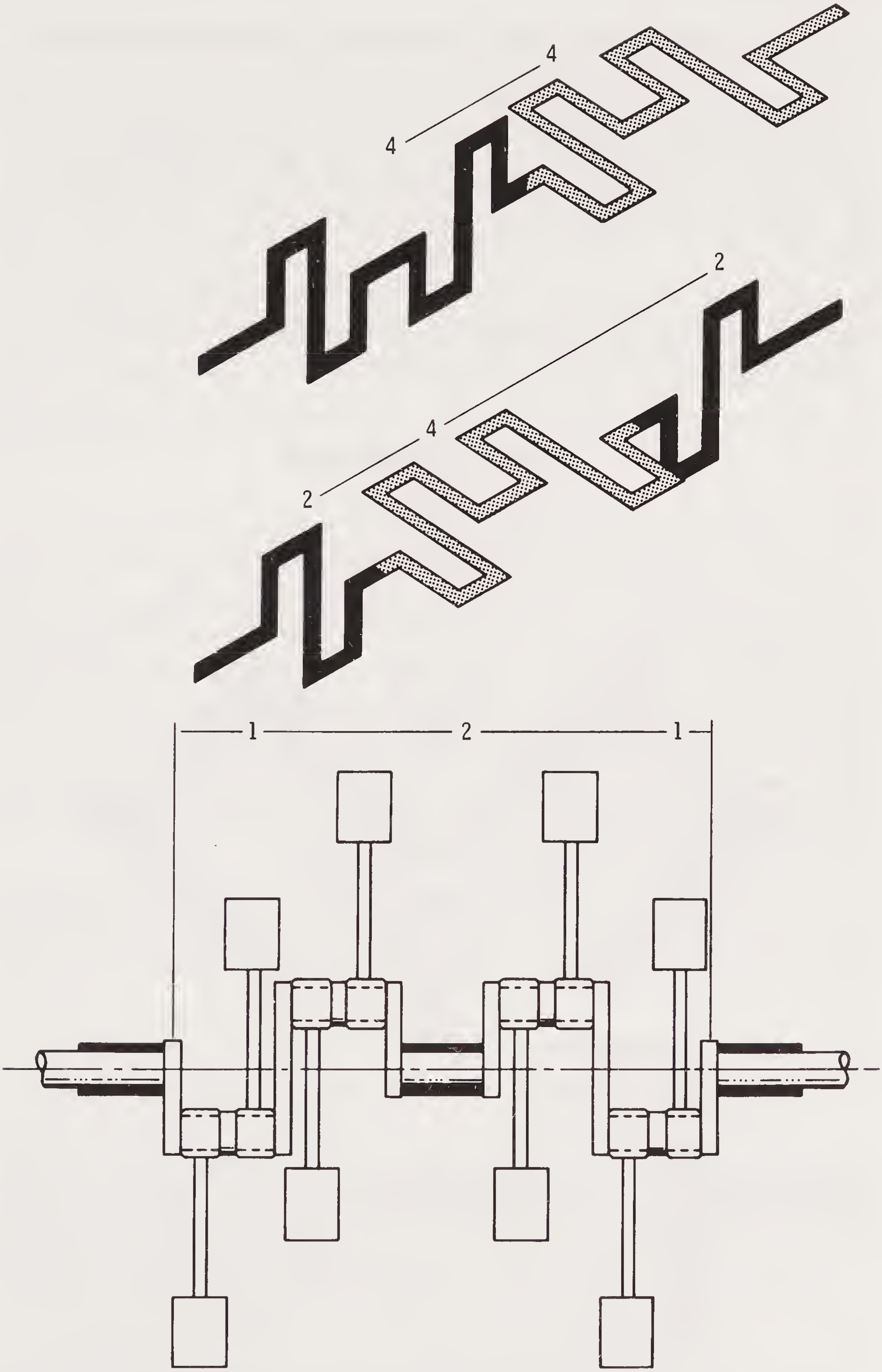



**Fig. 7-5. Two crankshaft arrangements for an eight-cylinder engine illustrating the 4-4 and 2-4-2 sequence.**

## BUILT-UP AND SINGLE-PIECE CRANKSHAFTS

The built-up type of crankshaft has each of its parts made separately and then jointed strongly together as by keyways and force fits, as in Fig. 7-6. Quite often, built-up shafts are fitted with ball bearings as they are the only kind of shaft that can be fitted with ball bearings if they have more than two bearings.

Such shafts are sometimes used on motorcycles where the two crank arms in the shape of discs may perform the functions of a flywheel and also act as counterweights.

## MAIN BEARINGS

The crankshaft of an engine rotates in the main bearings. These bearings are located at both ends and at a few intermediate points along the crankshaft. The main bearings are often channeled for oil distribution and may be lubricated with crankcase oil by pressure through drilled passages or by splash. To prevent loss of engine lubricating oil, oil seals are placed at the main bearings where the crankshaft extends through the crankcase. The number of bearings will depend upon the type of engine and number of cylinders, although a crankshaft for a given number of cylinders may be constructed for different numbers of bearings.

A one- or two-cylinder engine will have two main bearings, one front and one rear; the rear main bearing always being fitted adjacent to the flywheel. A four-cylinder engine normally has three

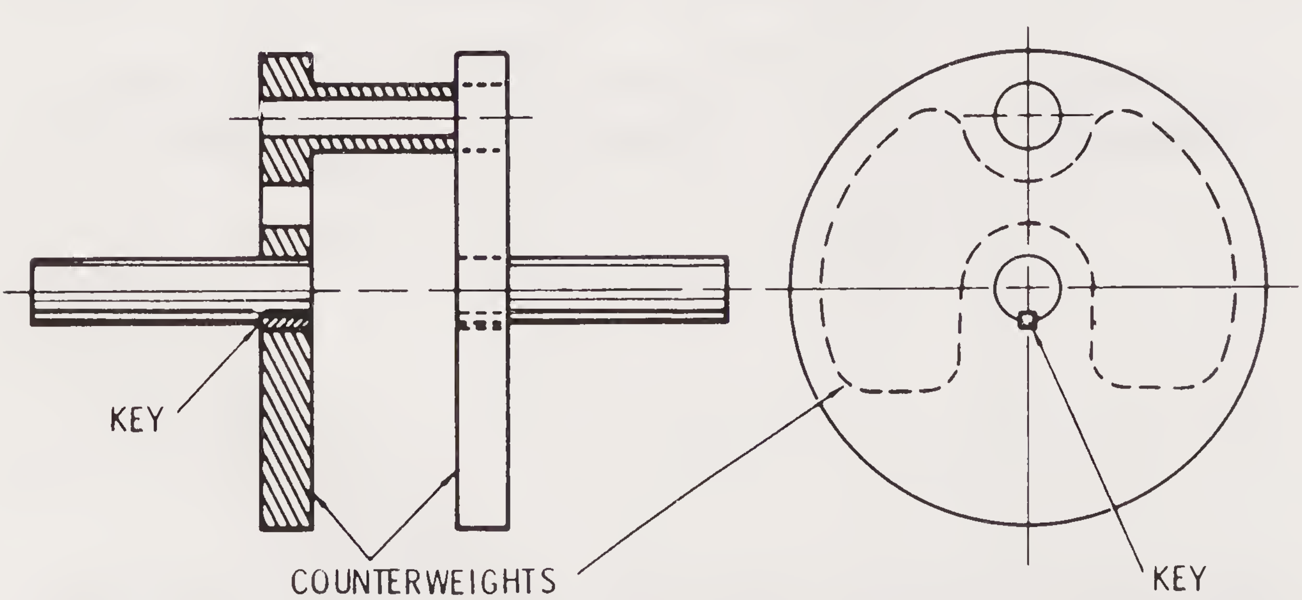



**Fig. 7-6. General construction of a disc, built-up, counterweighted shaft.**

bearings, one at the front, one between the cylinders and one at the rear.

The prevailing practice is to fit the bearings into the webs or ribs and ends of the crankcase. The bearings with this construction are upside down, so to speak, but are made accessible by removing the oil pan. The practice of manufacturers differs with respect to the number of bearings to be used.

A little consideration will show that a shaft for a given number of cylinders may be constructed for different numbers of bearings. For example, Fig. 7-4 shows how a 1-2-1 shaft for a four-cylinder engine could be designed for two, three or five bearings. The arrangement shown in Fig. 7-4A would require a shaft of very liberal

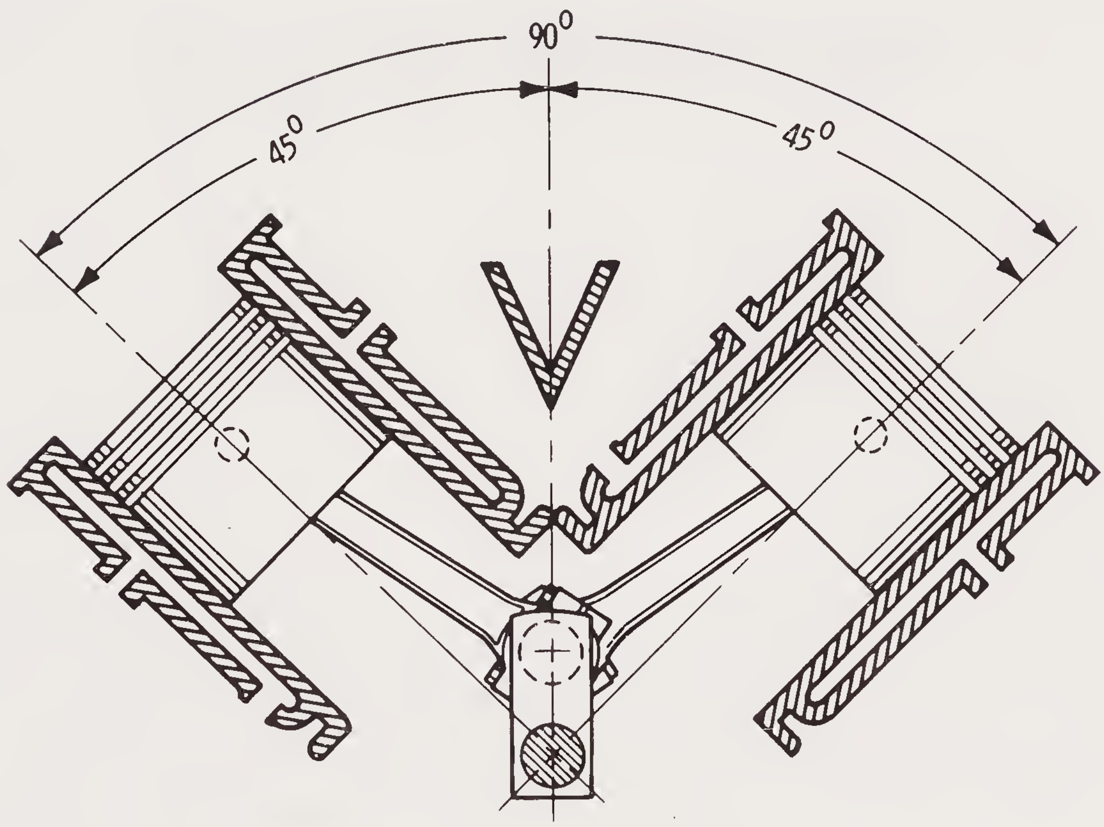



**Fig. 7-7. Angular arrangement of cylinders on a V-8 engine.**

diameter to resist the bending action and would not be as good as the three-bearing shaft shown in Fig. 7-4B. Eight-cylinder V-type engines are able to withstand having fewer bearings because of the angular arrangement of the cylinders (Fig. 7-7).

## CHAPTER 8

# Engine Flywheel

The purpose of the flywheel is to secure momentum necessary to keep the crankshaft turning when it is not receiving power impulses from the pistons. The flywheel will thus permit the engine to idle smoothly through those parts of the cycle when power is not being produced and to keep the engine turning at a nearly uniform rate of rotation.

It is self-evident from the foregoing that the heavier the engine flywheel is, the smoother the engine will idle. An excessively heavy flywheel, on the other hand, will cause the engine to accelerate and decelerate slowly because of its inertia. It is for these reasons that heavy-duty engines are built with large-inertia flywheels, and small high-speed engines have light flywheels. On engines equipped for electric starting, the flywheel rim carries a ring gear, either integral with the flywheel or pressed or welded on, which meshes with the starter driving gear for cranking the engine at starting.

Flywheels employed on small two- and four-cycle engines are

usually made of cast or forged aluminum alloy, the hub forming an integral part of the flywheel shell, or a steel hub is attached to the shell. On some engines of this type, the flywheel encloses a permanent magnet attached to its inner surface, which functions as a part of the ignition system (see Magneto Ignition, page 216). On air-cooled engines, the flywheel usually has fins on its outer surfaces that act as fans, promoting circulation of air over the cylinder. See Fig. 8-1.

## TORSIONAL VIBRATION

Torsional vibration is a twisting rotation, usually noticeable in in-line six- and eight-cylinder engines with long crankshafts. It is

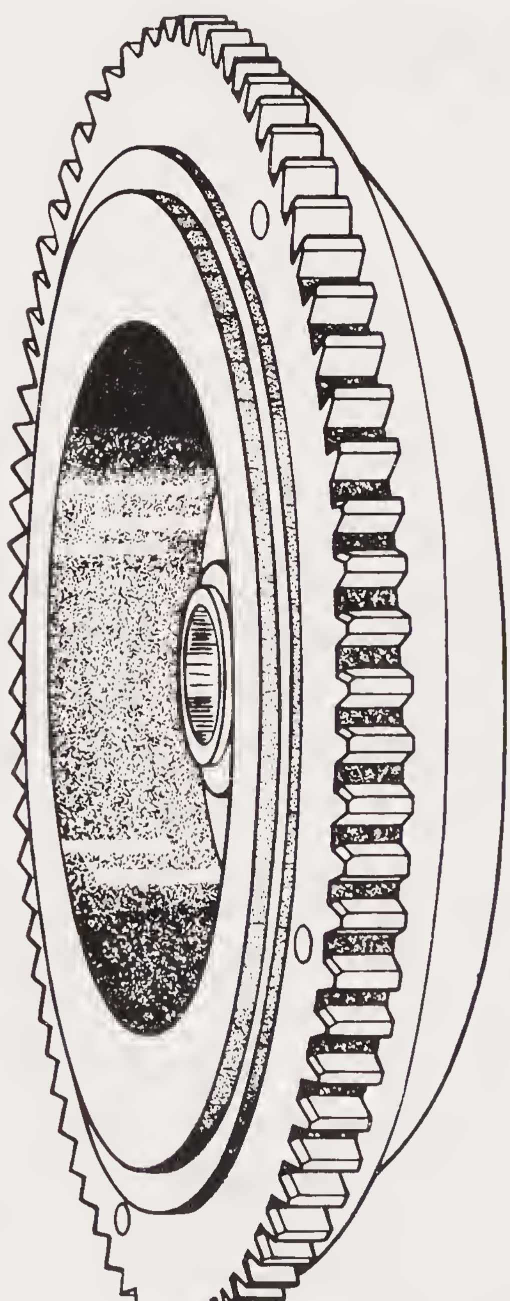


**Fig. 8-1. Typical gear-type flywheel.**

caused by the reciprocating movement of the piston acting on the rotating crankshaft.

Thus, for example, when the front cylinder is fired, it would turn the crankshaft very rapidly, but the inertia of the flywheel would tend to prevent this rapid increase in speed at the rear of the crankshaft.

The result is a "winding" or "twisting" action in the crankshaft. As the force exerted by the front cylinder decreases, this twisting action will cease. Although this twisting action is very small, it is nevertheless large enough to set up torsional vibration in the engine.

## CLASSES OF VIBRATION DAMPERS

Vibration dampers may be divided into two classes, as:

1. The flywheel type.
2. The harmonic balancer.

The flywheel type is simply a small, solid flywheel mounted on the front of the crankshaft. It functions in much the same way as the larger rear flywheel by storing rotating energy and, in doing so, resists sudden, fast twisting of the crankshaft.

The harmonic balancer is also a small flywheel mounted on the front of the crankshaft, but it has built-in flex. The flex may be designed in the form of a slip clutch, leaf spring or, most often, a rubber mount between the hub and outer weight ring. The purpose of the flexible connection is to enable the harmonic balancer to set up torsional vibrations opposite those created in the crankshaft, thus canceling them out.

CHAPTER 9

# Valves and Valve Gears

Every cylinder of any four-stroke-cycle engine must have at least one intake and one exhaust valve: the intake valve permits the mixture to enter the cylinder, and the exhaust valve allows the burned gases to escape.

The type of valves usually employed in internal combustion engines are called *poppet* or *mushroom* valves, the word *poppet* being derived from its action (it pops in and out) and the word *mushroom* from its general appearance or shape.

With reference to Fig. 9-1, the poppet valve consists essentially of a disc around the circumference of which is a face which provides a ground joint seal with the valve seat. Projecting from the center is a stem which holds the valve in place centrally and transmits the movement of the valve gear to the valve.

The valves are usually made in one piece from special alloy steel. The exhaust valves especially are made of chromium-nickel

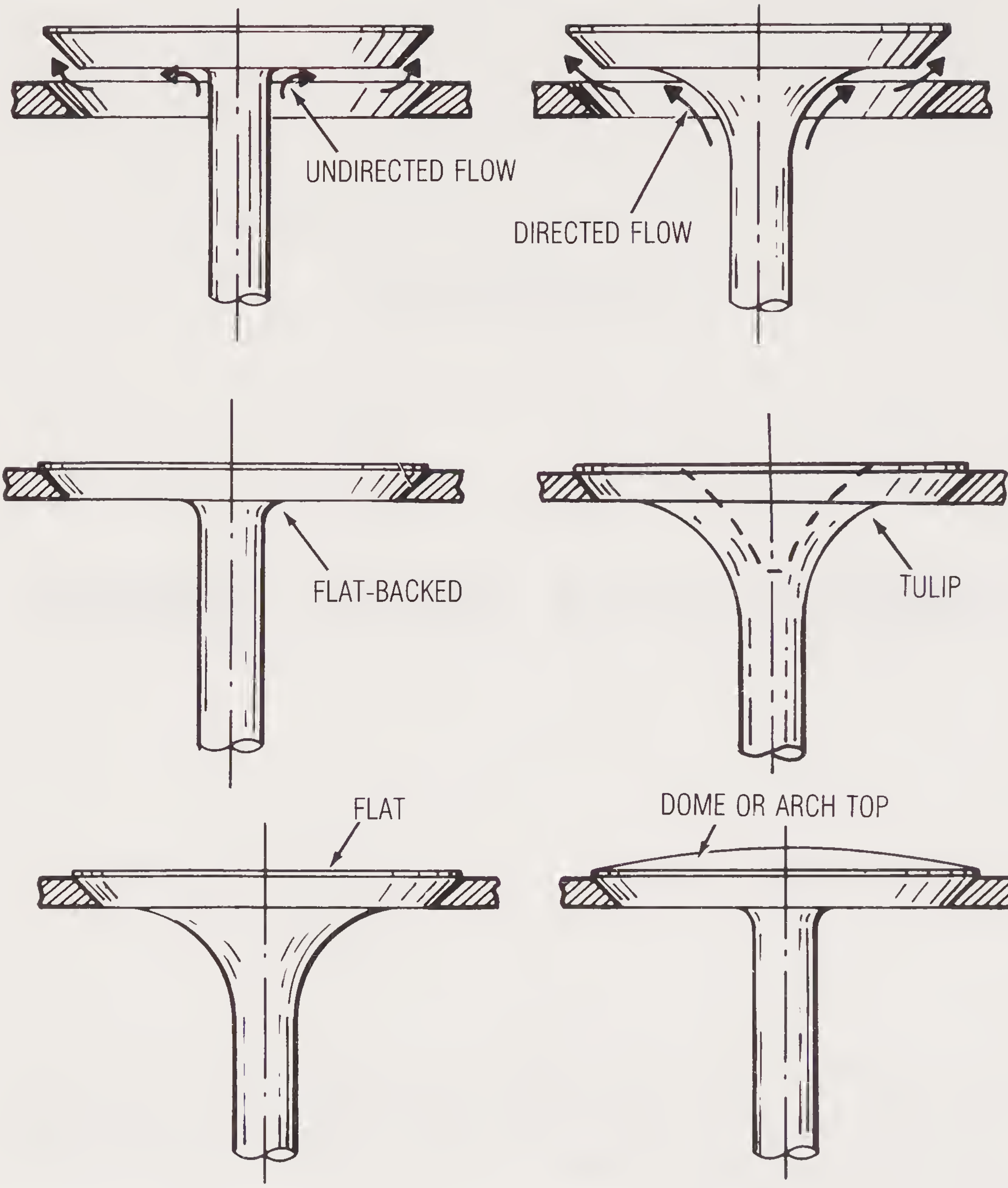



**Fig. 9-1A. Valve shapes.**

alloy or silichrome alloy because of the extremely high temperature they must withstand. In some engines, particularly the air-cooled types, the exhaust valve contains sodium in a sealed cavity extending from the head through the stems from which it is conducted to the valve guide, thus aiding in cooling.

## VALVE SEATS

The matched circular surface upon which the valve face rests and which is a part of the opening leading into the combustion chamber

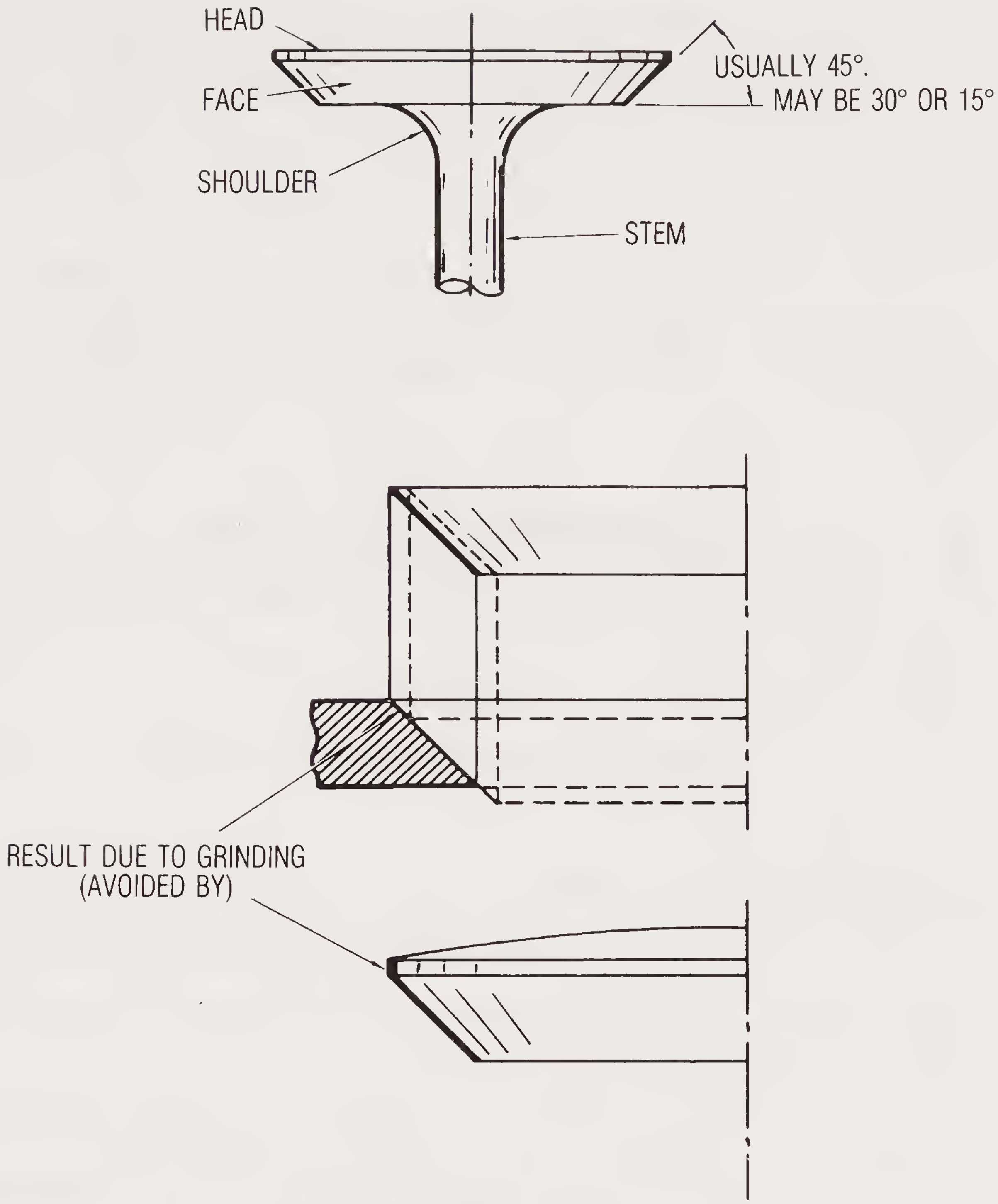



**Fig. 9-1B. Valve details.**

of the cylinder is termed the *valve seat.* There are at least two such openings or ports in each cylinder, to which are connected the intake and exhaust manifolds. Since valve seats are subjected to intense heat, valve grindings and reseating are usually necessary from time to time to renew the sealing surfaces.

## VALVE STEM GUIDES

The function of the valve stem guide, as the name implies, is to guide the valve stem during its reciprocating motion, actuated by

the cam on the camshaft. The guides may be an integral part of the cylinder block or cylinder head, depending on the type of valves used, or they may be removable sleeves that can be replaced when worn. Removable valve guides are usually made of cast iron, although bronze has been used in some engines because of better protection against seizing.

The valve stems are ground to fit the guides in which they operate, and the reamed hole in the guide must be aligned and square with the valve seat to ensure proper seating of the valve face.

## CAMSHAFTS AND CAMS

The camshaft in its simplest form is a straight shaft on which eccentric lobes or cams are forged as an integral part. In multiple-cylinder engines there are ordinarily as many cams as there are valves to be operated. A one-cylinder, four-stroke-cycle, poppet-valve engine would have two cams, one for the intake and one for the exhaust valve.

In order for the engine to operate properly, the cams must have the proper location on the shaft and must be designed to lift the valves at precisely the correct instant of piston travel and hold it open just long enough to obtain the most efficient fuel intake and exhaust of the cylinder. See Fig. 9-2.

If the camshaft is chain or belt driven, it rotates in the same direction as the crankshaft, but if driven by a gear meshed with the gear on the crankshaft, the camshaft rotation is opposite from that of the crankshaft.

The rapidity with which the valves open and close is determined by the slope of the acting surfaces between the lobe and lifter, that is, the slope of the opening and closing faces of the cam. See Fig. 9-3.

## HOW TO DESIGN A CAM: FUNDAMENTALS

The operations necessary in laying out a cam to operate a valve under specified conditions are complicated. Cam action has its limits

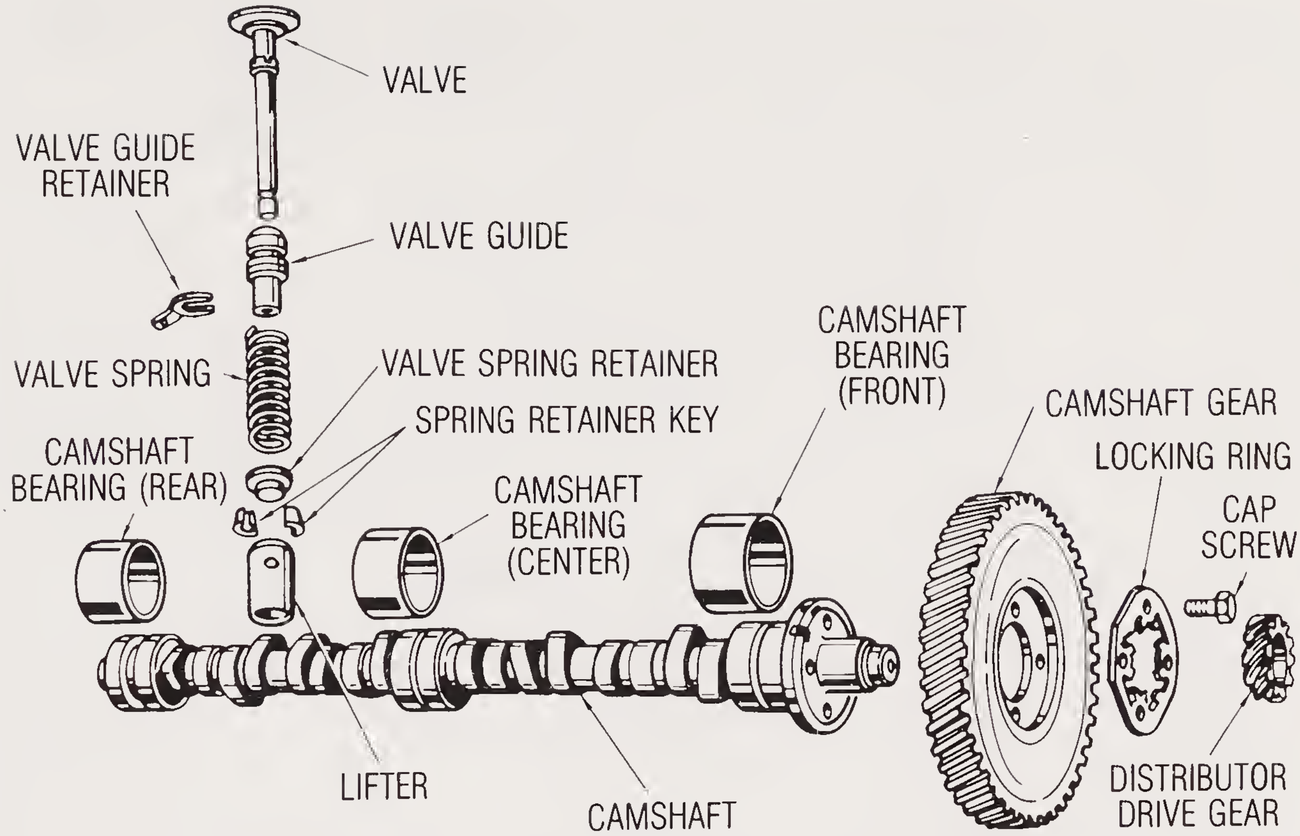



**Fig. 9-2. Camshaft and associated parts.**

and the conditions must be met or noisy and quick-wearing cam lobes will occur. There are some basic or fundamental facts that should be considered in any cam design.

No matter how desirable quick action in opening and closing the valves may seem, the opening and closing faces should meet the hub circle tangentially, that is, there should be no abrupt change of direction of the acting surface. This is especially important on the opening face because here the tension of the spring, 40 lb. or more, opposes any sudden starting of the valve when it begins to open. Another point is that the steeper the opening face, the more the lateral thrust on the follower, which increases the friction and wear.

**Example:** *Design a varying continuous-motion cam to operate an intake valve under the following conditions: Lift* $^{11}/_{32}$*, arc* $^{5}/_{16}$*, intake period 240°, the cam to have quick acceleration in opening and closing. Since the intake period is 240 crankshaft degrees, on the camshaft, which runs at half crankshaft speed, the camshaft degrees will be* $240 \div 2 = 120°$.

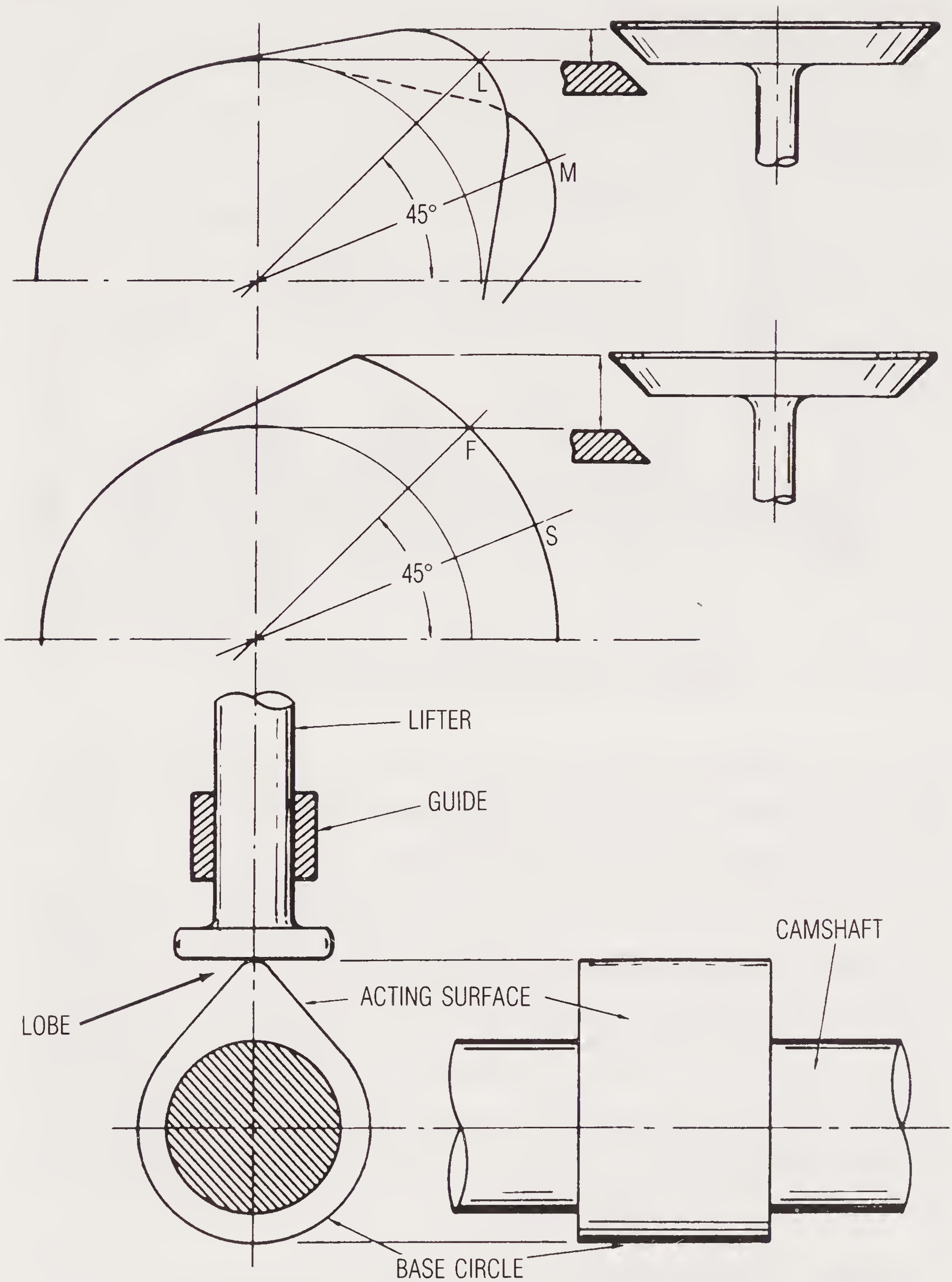



**Fig. 9-3. Comparison of different cam lobes and valve openings.**

## Solution

In Fig. 9-4B, first draw the horizontal and vertical axes. Through the center O, draw *Aa*, and *Bb*, so that the angle AOB is 120°, laid

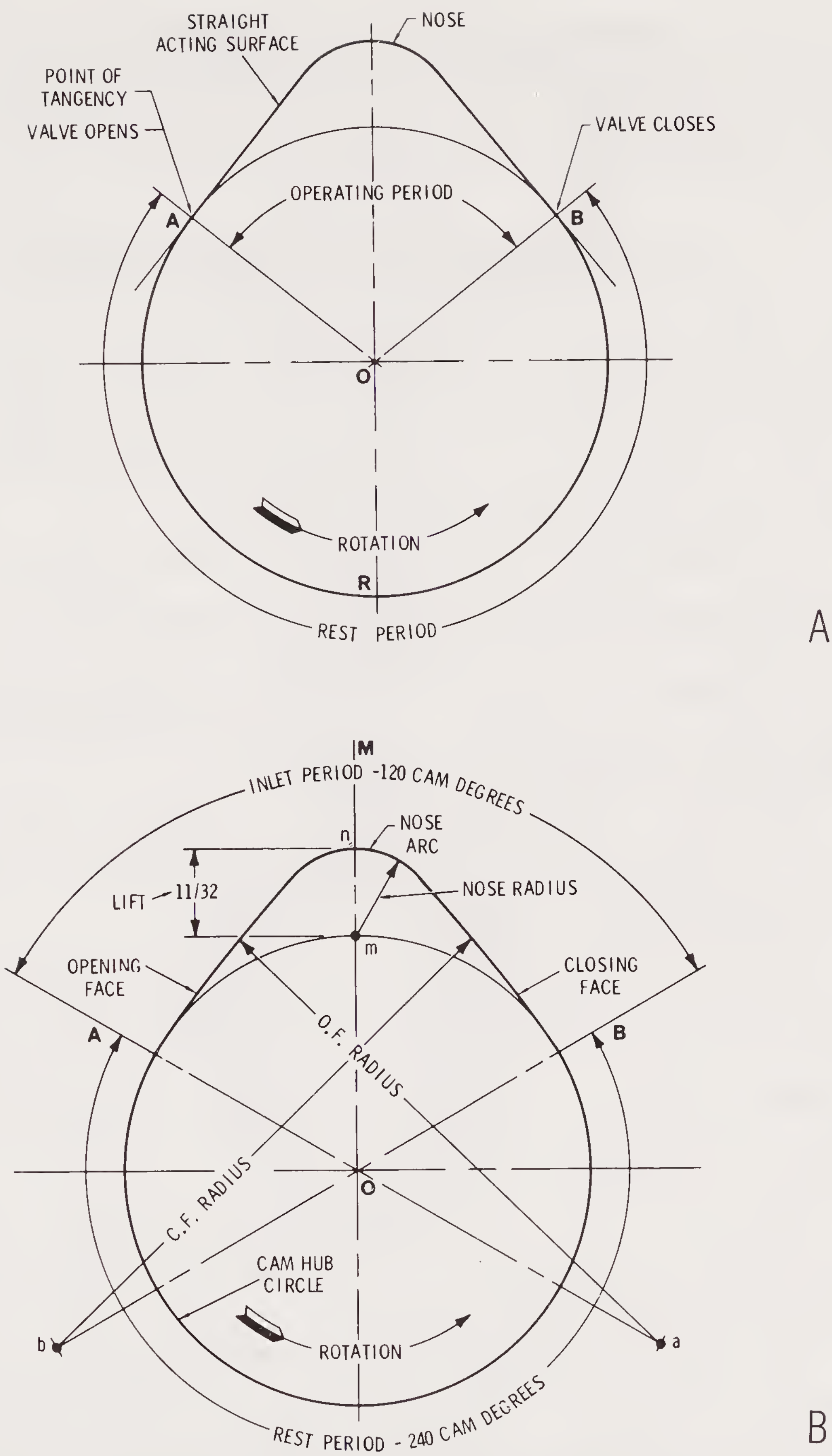



**Fig. 9-4. Design of cam with curved opening and closing faces.**

out so that the vertical axis OM bisects the angle AOB, that is, < AOM = 60° and <BOM = 60°. Take the diameter of cam hub circle, say, 1½ in. From *m* lay off lift = 11/32 in. With center on axis OM, describe through point *n* nose arc with radius = 11/32 in. On

*Aa*, find by trial center of a circle that will be tangent to the hub circle and also tangent to the arc; describe the arc connecting them which gives the contour of the opening face. The shape of the closing face is identical and is obtained in the same way.

## VALVE-OPERATING MECHANISM

The function of the valve-operating mechanism is to control the opening and closing of the engine valves at the correct instant of the cycle. The camshaft is rotated by the engine crankshaft by means of gears, belts or chains. The two shafts are therefore kept in a direct speed relationship with one another.

The mechanism used to operate the valves is shown schematically in Fig. 9-5. Here the cam **A** is the driving member and receives its motion from the main shaft through two gears, although sometimes an idler is interposed between the crankshaft and camshaft gears. The cam turns half as fast as the main shaft since it takes two revolutions to complete the four-stroke cycle.

The cam, as it revolves, transmits motion to lifter **B**, which works in a closely fitting guide to prevent any lateral motion as the cam slides across the bottom of the plunger.

To prevent wear due to the cam rubbing the same part of the lifter bottom, the cam is located off the center of the lifter so as to turn the lifter to a new position each revolution of the cam. Thus the lifter not only reciprocates up and down, but turns through a small arc each time it engages with the cam. The lifter **B** is variously called tappet, follower, etc.

Forming a part of the plunger is the clearance adjustment mechanism consisting of a case-hardened bolt, **C**, threaded into the top of the plunger and secured by a locknut.

The requirements of a valve spring are that it will exert sufficient force to seat the valve firmly to ensure tightness and to give sufficient acceleration in closing, so that the valve will follow the motions imparted by the gear at highest possible speed. The strength required brings a sizable load on the lifter and cam. Hence it should not be any stronger than necessary to avoid excess friction and wear.

Various locking devices are used to retain the spring in a partly compressed position on the valve stem. Fig. 9-5 shows a spring cup or seat held in position by a pin passing through a hole in the valve

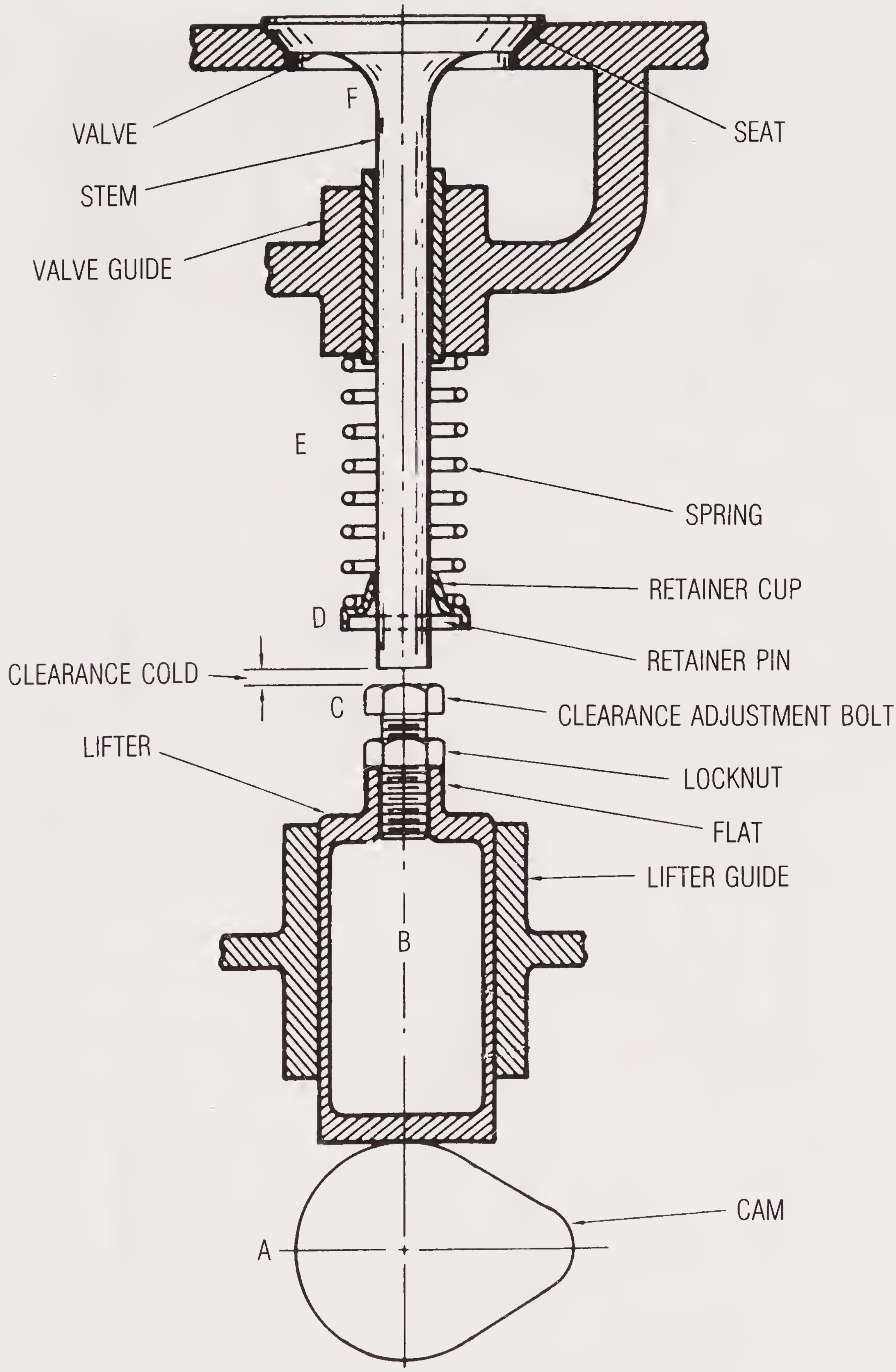



**Fig. 9-5. The valve gear assembly.**

stem. **E** is the spring and its function is to hold the valve closed except when pushed off its seat by the plunger. To properly operate the valve in closing, the spring must be quite stiff.

The valve is shown at **F**. The stem passes through a guide which

serves to hold the valve in a central position with respect to its seat, thus assuring that the valve will properly seal in closing. Fig. 9-6 illustrates the valve, a roller-type lifter used on heavy-duty and competition engines and rocker arm assembly used with overhead valves.

Many modern engines have advanced to overhead camshaft designs (Fig. 9-7). In these designs the camshaft is mounted on top of the cylinder head and is usually driven by a belt or a chain. The

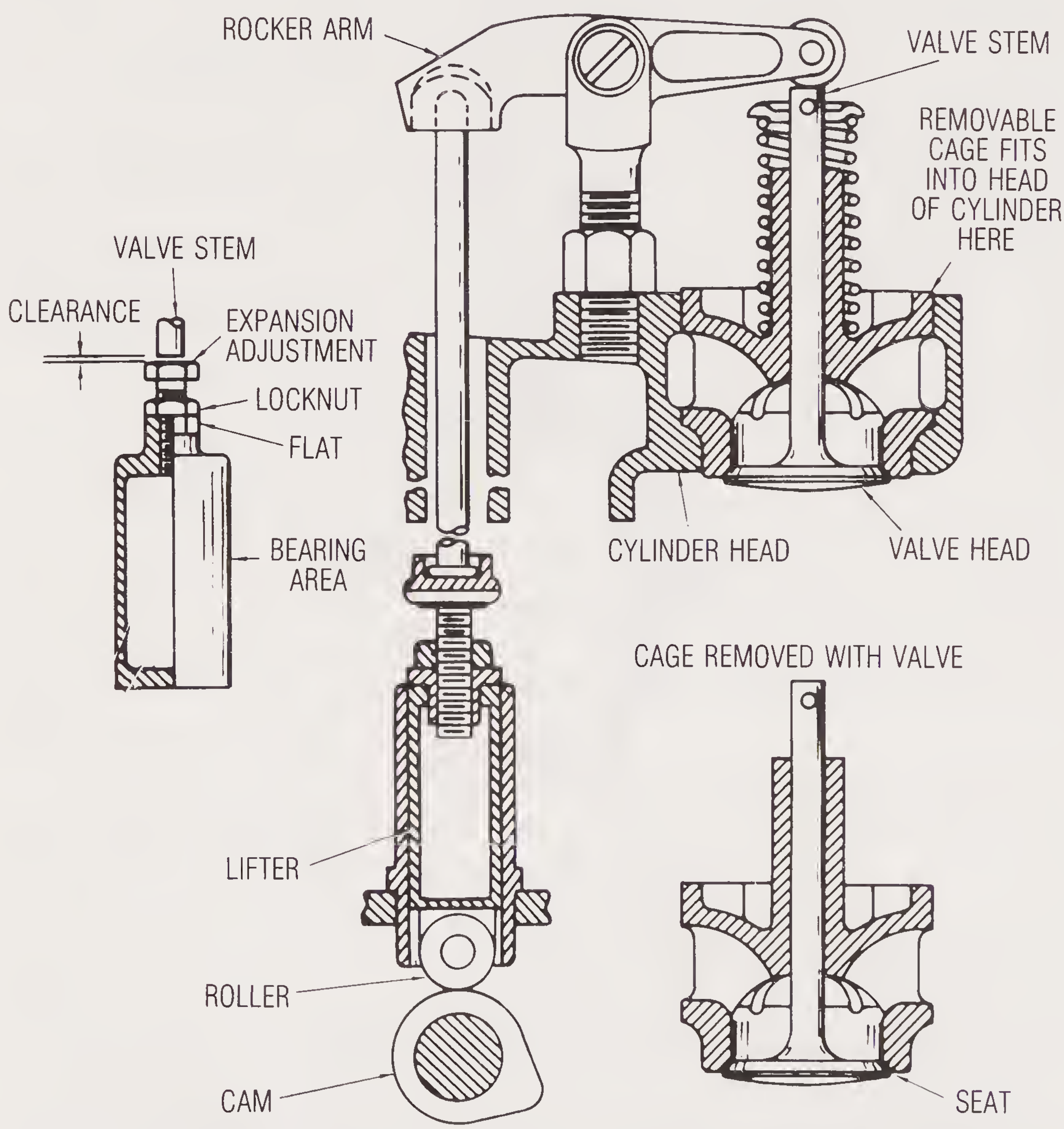



**Fig. 9-6. Valve lifter and rocker arm assembly.**

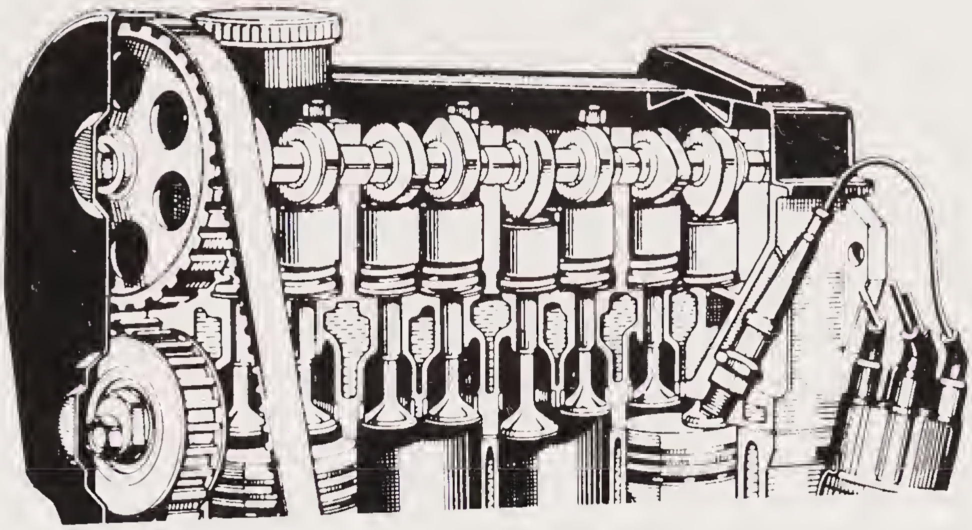


Fig. 9-7. Overhead cam system.

primary advantage is the omission of the push rods and rocker arms, decreasing the weight and number of moving valve train components. This allows for higher engine rpm and softer valve springs while retaining the advantages of the overhead valve engine.

CHAPTER 10

# Valve Timing

The expression *timing the valves* of a gas engine applies both to the valves and the ignition system. As previously noted, the valves must be timed to open and close at precisely the proper instant; otherwise the sequence of events of the working cycle would be disturbed and the engine would not operate satisfactorily, or at all, depending upon how much the timing was off.

*Valve timing*, therefore, refers to the exact times in the engine cycle at which the valves trap the mixture and then allow the burned gases to escape. The valves must open and close so that they are constantly in step with the piston movement of the cylinder which they control.

The position of the valves is determined by the camshaft and the position of the piston by the crankshaft. Correct valve timing is obtained by the proper relationship between the camshaft and the crankshaft. See Fig. 10-1.

The extreme accuracy with which it is desired to open and close

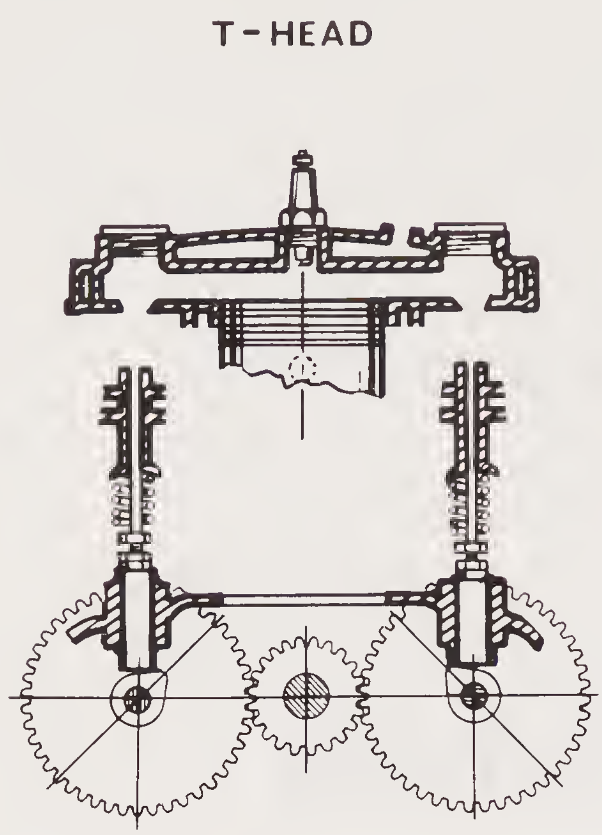



**Fig. 10-1. Valve gear assembly for T-head.**

the valves may be comprehended when consideration is given to the speed at which the valves of a modern high-speed engine operate. This is the primary reason for *valve overlap*, which simply means that the intake and the exhaust valves may both be open at the same time in any one cylinder. The valve overlap is necessary in order to compensate for the time required by the air or gas to flow through the manifolds.

A valve diagram for a typical high-speed engine is shown in Fig. 10-2. It will be noted in the diagram that the intake valve opens 15° before top dead center, while the exhaust valve does not close until 10° after bottom dead center. Both intake and exhaust valves are therefore open during 25° of the crankshaft rotation.

The instant at which a valve begins to open or when it closes (that is, leaves or comes into contact with its seat respectively) may be expressed in terms of:

1. Distance moved by the piston from top or bottom dead center.
2. Degrees the flywheel has turned with reference to top or bottom dead centers.

Timing is usually expressed in degrees, and marks are placed on the flywheel and the camshaft gear (Fig. 10-3) by the engine manufacturer to facilitate the timing operation. On most engines,

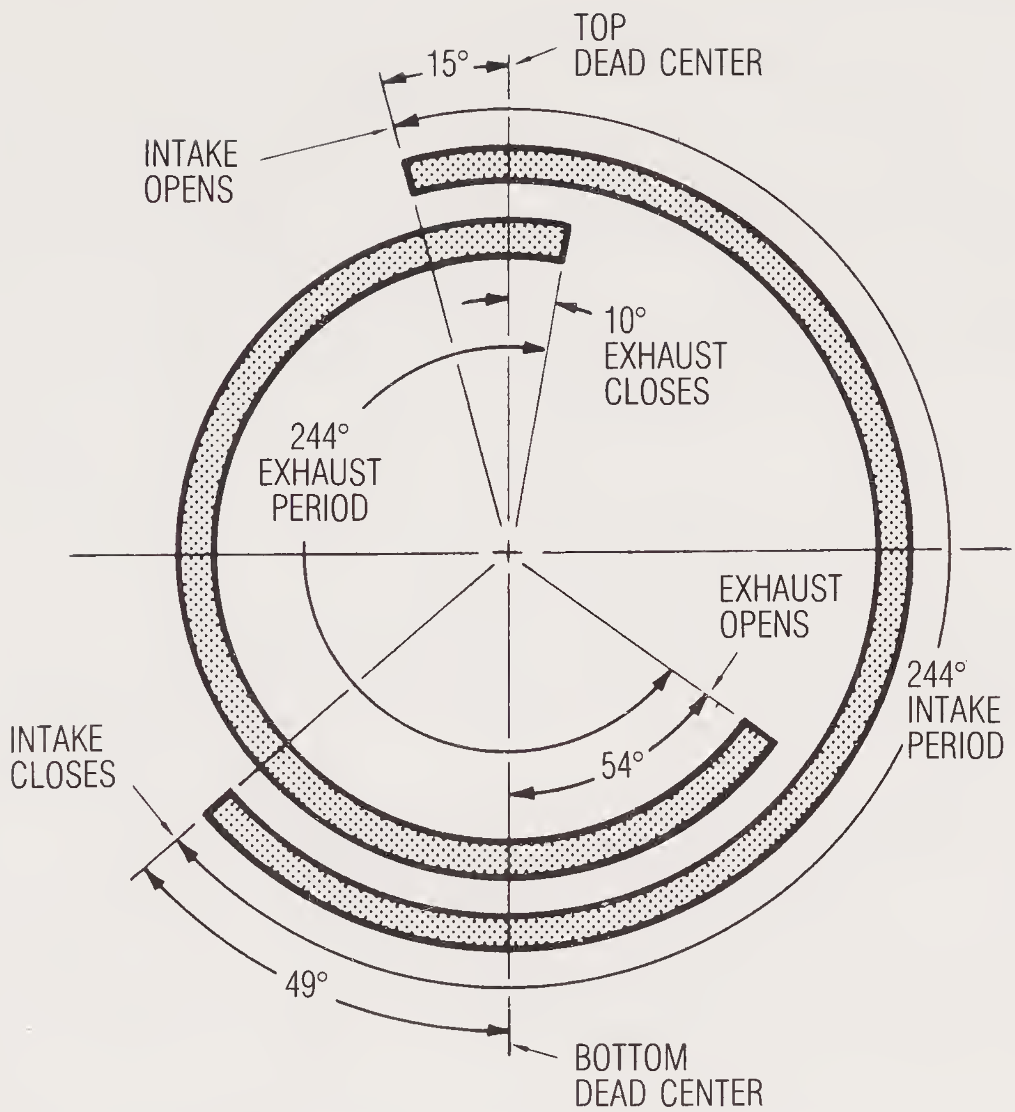



**Fig. 10-2. Typical valve timing diagram.**

the timing marks on the flywheel and camshaft gear, respectively, are so located that a straight line drawn through their centers will intersect both.

## HOW VALVES ARE TIMED

The instant of opening and closing of a valve is controlled by the angular position of the cam. Since the half-speed camshaft is driven a gear on the main shaft, evidently the timing may be changed by altering the position of the camshaft gear with respect to the main shaft gear.

The correct meshing positions of the two gears have already been determined by the manufacturer and the two gears marked so that when they are meshed with the marks opposite each other, they are correctly set. See Fig. 10-3. The half-speed camshaft gear and the crankshaft gear are known as the timing gears.

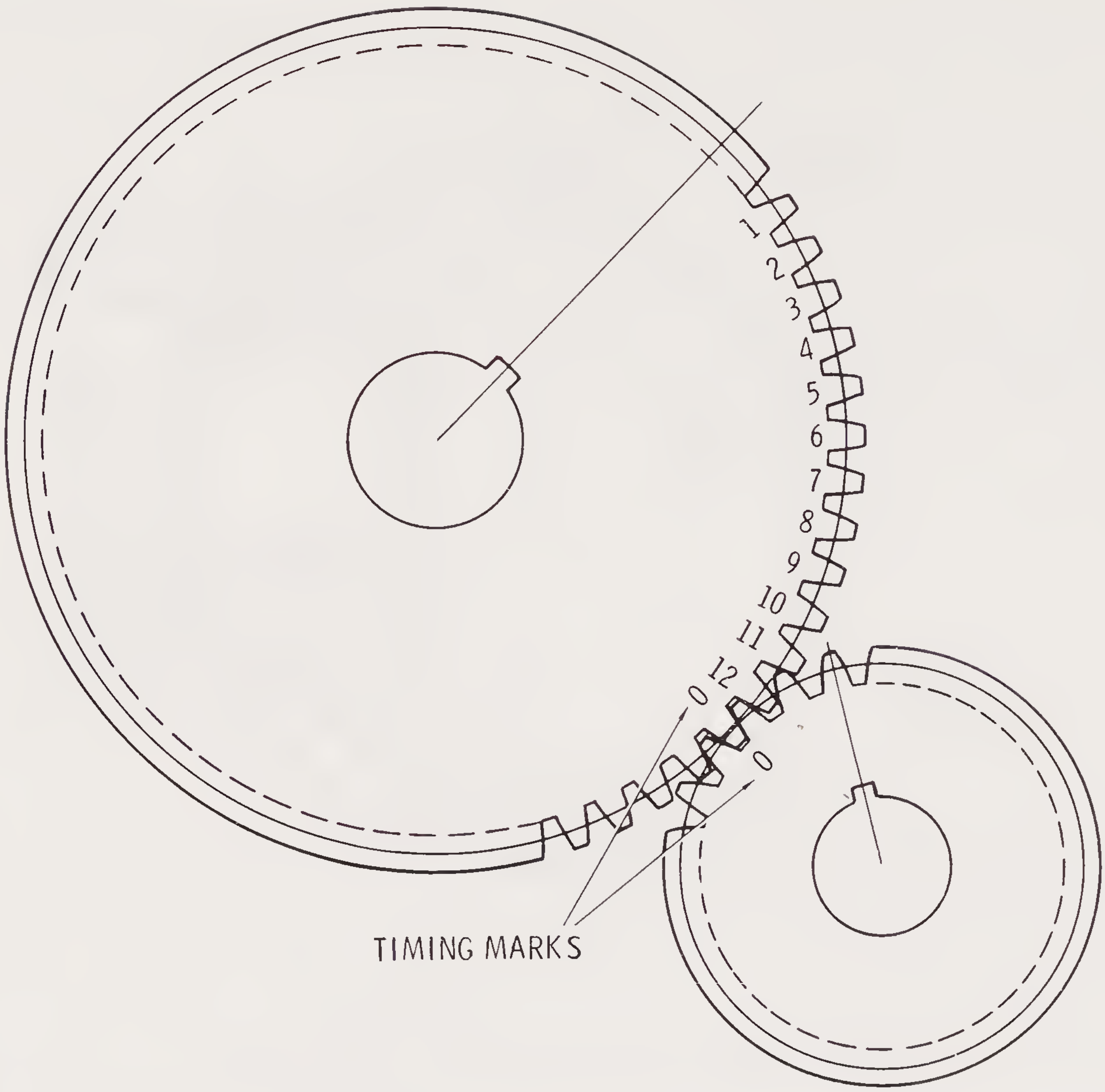



**Fig. 10-3. Timing gear assembly showing timing marks.**

Where the intake and exhaust valves are operated by separate camshafts, there are two half-speed gears and evidently each must be timed separately. With arrangements such as those found on T-head engines, both sets of valves may be out of time with each other, and at the same time be out of time with the pistons, or one set may be in time with the pistons, while the other set is out of time.

The valves may all be considerably out of time and the engine will still run, but at the expense of reduced power, increased fuel consumption and excessive vibration.

As just explained, timing of the valves is controlled by the relative positions of the timing gears. Allowance, however, must be made for the clearance between the lifter and valve stem; that is, the cam of the valve to be opened must turn through an arc sufficient

to raise the tappet a distance equal to the clearance before the valve will begin to open.

With tappets adjusted to minimum clearance, this lost motion is very small and need not be considered unless it is desired to time valves to the last degree of precision.

The operations necessary to time the valves on an engine that has intake and exhaust cams on the same shaft are:

1. Locating engine on dead center.
2. Determining correct position of the camshaft.

As a preliminary, adjust lifters to the specified clearance. After the valves are timed, this clearance will have to be readjusted with the engine hot to allow for expansion—unless the clearance is given for a cold engine.

In practically all cases there are markings on the flywheel and a pointer provided to locate engine on dead center. In addition, there are marks on the the timing gears to determine the correct position of the camshaft. In the absence of such markings, the dead center and angular position of the camshaft must be determined.

## HOW TO FIND THE DEAD CENTERS

Anchor at some convenient point on the engine an indicator or pointer terminating at the rim of the flywheel. Turn flywheel till crank is 10° to 20° off top dead center and measure from a convenient point of reference the distance from the piston to this point. Make a mark on the flywheel opposite pointer. Again turn the flywheel till crank comes on other side of top dead center and piston has traveled the same distance.

Put a permanent mark on the flywheel rim halfway between the pointer and the first mark. Identify the permanent mark by stenciling the letters T.D.C. and also the cylinder number. Thus, if it is cylinder No. 1, the marking will be T.D.C.1. This mark is the dead center, and when the engine is turned until the mark registers with the pointer, it is on the dead center.

In turning the flywheel each side of the dead center, it should be turned in a direction so that the crank pin will bear against the same half of the bearing to avoid any error due to lost motion.

## DETERMINING CORRECT POSITION OF THE CAMSHAFT

Turn flywheel until piston is at beginning of the intake stroke. This is indicated by the movement of the lifter in opening the intake valve. Note from manufacturer's instructions the number of degrees before or after T.D.C. for timing of the intake valve. These degrees must be converted into inches on the flywheel rim to determine how far the flywheel must be turned to correspond.

**Example** *If the valve setting is to be for 8° preadmission and the diameter of flywheel is 12 in., how many inches on rim must the wheel be turned for this setting?*

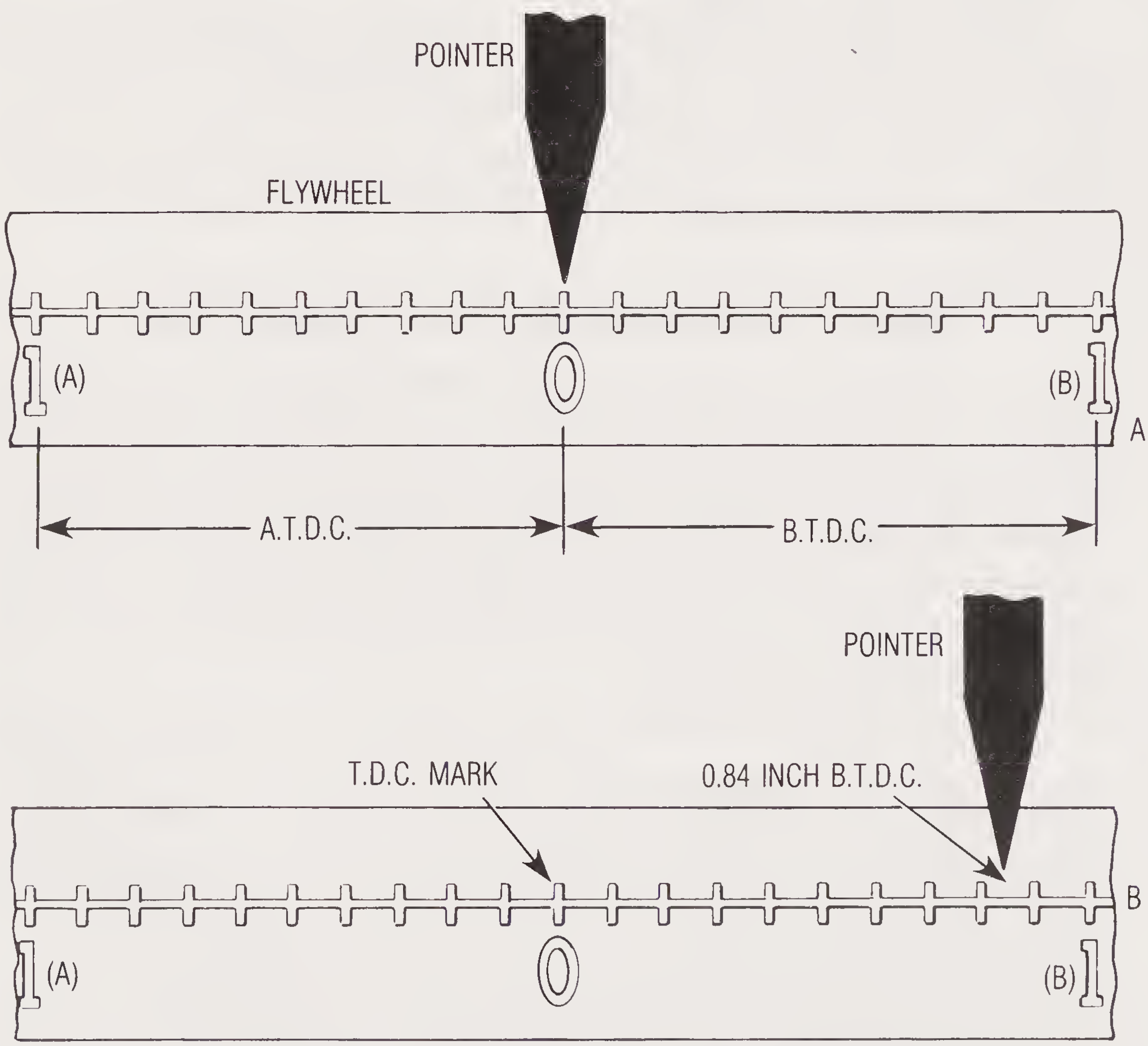



**Fig. 10-4. Degrees converted to inches on flywheel or balancer.**

## Solution

$$\text{Inches to be turned} = \frac{\pi D \phi}{360}$$

$$\begin{aligned} \text{in which } D &= \text{diameter of flywheel in inches} \\ \pi &= 3.1416 \\ \phi &= \text{intake degrees} \end{aligned}$$

Substituting,

$$\text{Inches to be turned} = \frac{3.1416 \times 12 \times 8}{360} = 0.84$$

Accordingly, on the flywheel lay off an inch on either side of the T.D.C. permanent mark and divide into tenths, as in Fig. 10-4A. Since 8° crank rotation corresponds to 0.84 in. on the flywheel, the T.D.C. mark must be turned this distance from the pointer. Since, in operation, the top of the flywheel rotates from left to right, the T.D.C., or zero, mark must be turned to the left the required distance, as in Fig. 10-4B, because intake begins 8°, or .84 in., on the flywheel before top dead center.

## CHAPTER 11

# Lubricating Systems

The lubricating system forms an important part of any engine, because if not lubricated properly, the engine cannot run for any length of time without serious damage.

The primary function of engine lubrication is to reduce the friction between the moving parts. Lubrication also assists in carrying heat away from the engine, cleans the engine parts as they lubricate, and forms a seal between piston rings and cylinder walls to prevent blow-by of combustion gases.

The various types of lubrication systems employed in internal combustion engines are:

1. Forced lubrication.
2. Splash lubrication.
3. Oil feed with fuel.

Forced lubrication by pump pressure is the prevailing method in large high-speed engines, although some engines use a combination of splash and force. In the splash system, the engine parts strike the oil in the reservoir and splash it around over the other parts in the crankcase. The lubrication thus supplied is part fluid and part oil mist.

*A two-stroke-cycle engine* has no oil reservoir and no specific oiling system. It consists simply of mixing oil with fuel in certain specified amounts, and as the fuel circulates in the form of vapor in the engine crankcase, the heavier oil separates from the fuel and is carried to the working parts in the form of an oily mist.

## FORCED LUBRICATION

In this system of lubrication the oil is drawn from a reservoir in the oil pan of the engine by a circulating pump usually of the rotary gear type. From the pump it is forced under pressure through oil passages to the camshaft, bearings and main bearings.

From the main bearings the oil is forced under pressure through holes bored in the crankshaft to the connecting rod bearings. From the latter bearings it may again feed through oil passages in the connecting rod to the wrist pins. Oil escaping from the wrist and crank pins lubricate the cylinders, piston and piston rings. Lubrication of the valve mechanism in an overhead valve engine is accomplished by oil pumped to the hollow rocker arm shafts.

After having passed through the various bearings the oil is returned to the sump, where it reenters the pump and circulates again as previously described. For the guidance of the engine operator, an oil pipe usually connects the oil pressure line with a pressure gauge mounted in a suitable location.

## COMBINATION LUBRICATING SYSTEMS

In the combination system, oil is under pressure directly to the main bearings through oil passages. Positive pressure may also provide for lubrication of the camshaft. Connecting rod bearings are lubricated by dippers on the rod bearing caps, which dip into oil-

filled troughs in the oil pan. The dippers also splash oil up into the cylinders and over the pistons and cylinder walls.

## OIL PUMPS

Oil pumps are mounted either inside or outside of the crankcase, depending on the design of the engine. They are usually mounted so that they can be driven by a worm or spiral gear directly from the camshaft or crankshaft.

There are three general classes of oil pumps, namely: the *gear, vane* and *plunger*. In the gear-type pump, oil is forced into the pump cavity, around a gear set, and out the other side into the oil passages. The pressure is derived from the action of the meshed gear teeth, which prevents oil from passing between the gears, and instead forces it around the outside of each gear. See Fig. 11-1.

The general arrangement of an oiling system is shown in the elementary illustrations, Figs. 11-2 and 11-3. Fig. 11-2 shows an oil pump and connections for lubricating the main and connecting rod bearings, including the oil filter. The method of lubricating the connecting rod, wrist pins and cylinder walls is shown in Fig. 11-3.

In Fig. 11-2, it will be noted that the pump is driven by the camshaft through spiral gears. This gear also serves as drive for the distributor, which is coupled to the pump shaft.

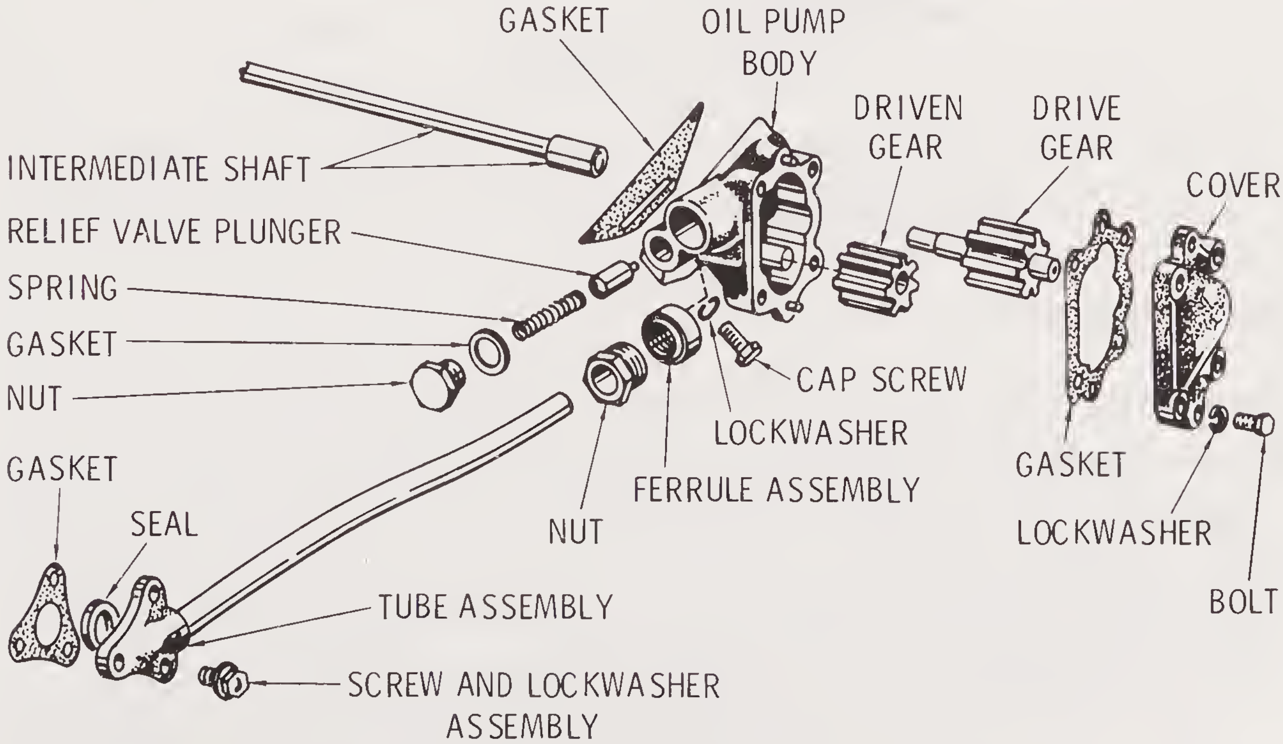



**Fig. 11-1. View of a typical gear-type oil pump.**

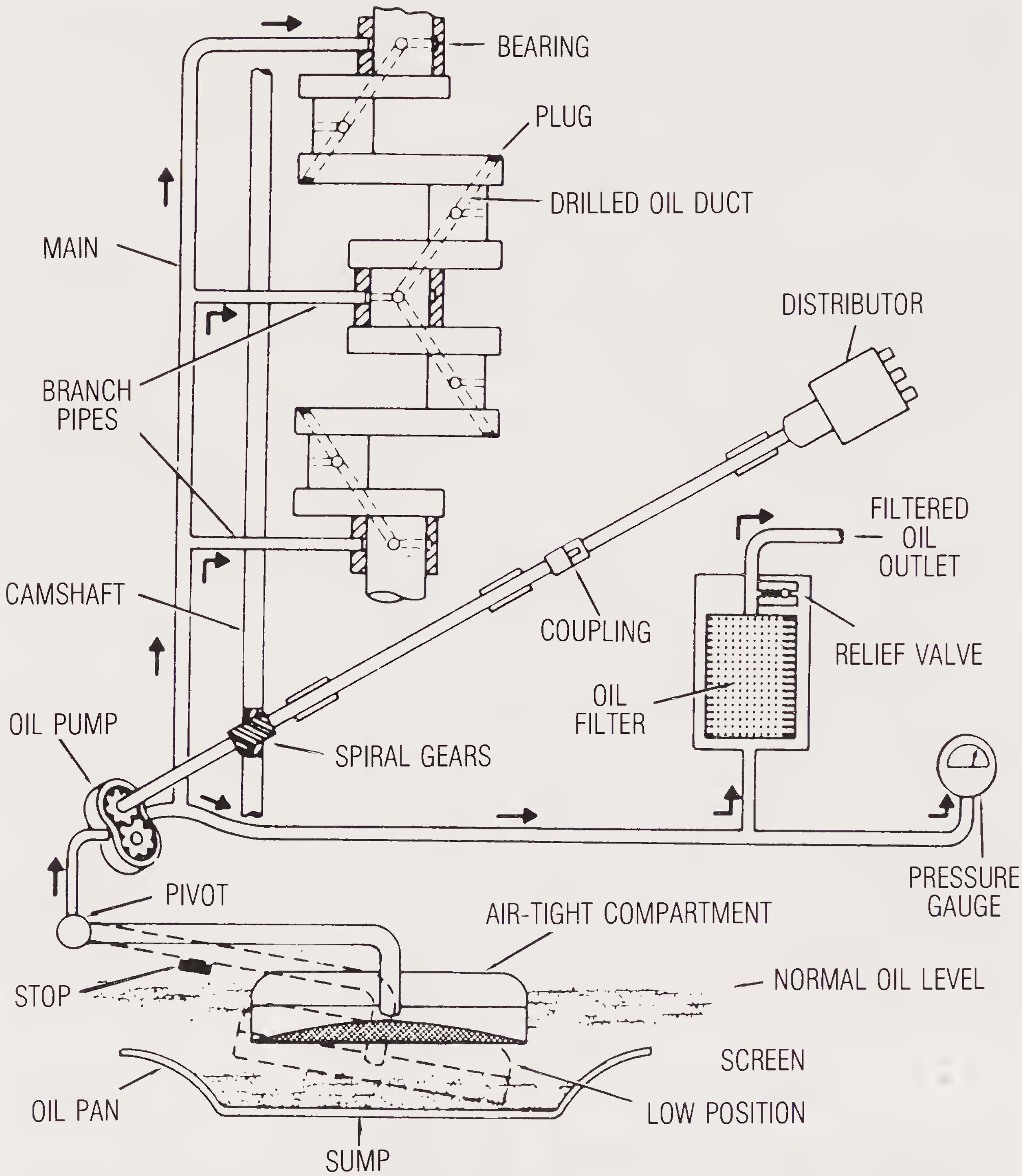



**Fig. 11-2. Elementary diagram of a full-pressure lubrication system.**

## Oil Strainers

The oil strainer is usually a fine-mesh bronze screen located so that oil entering the pump from the oil pan must flow through it. The strainer may be hinged to the oil pump inlet so that it floats on top of the oil. Thus, all oil taken into the pump comes from the surface. In this way it prevents the pump from drawing oil from the bottom of the oil pan where dirt, water and sludge are likely to collect.

Most oil strainers are designed so that they will be collapsed by high oil pressure if they become clogged, thereby preventing

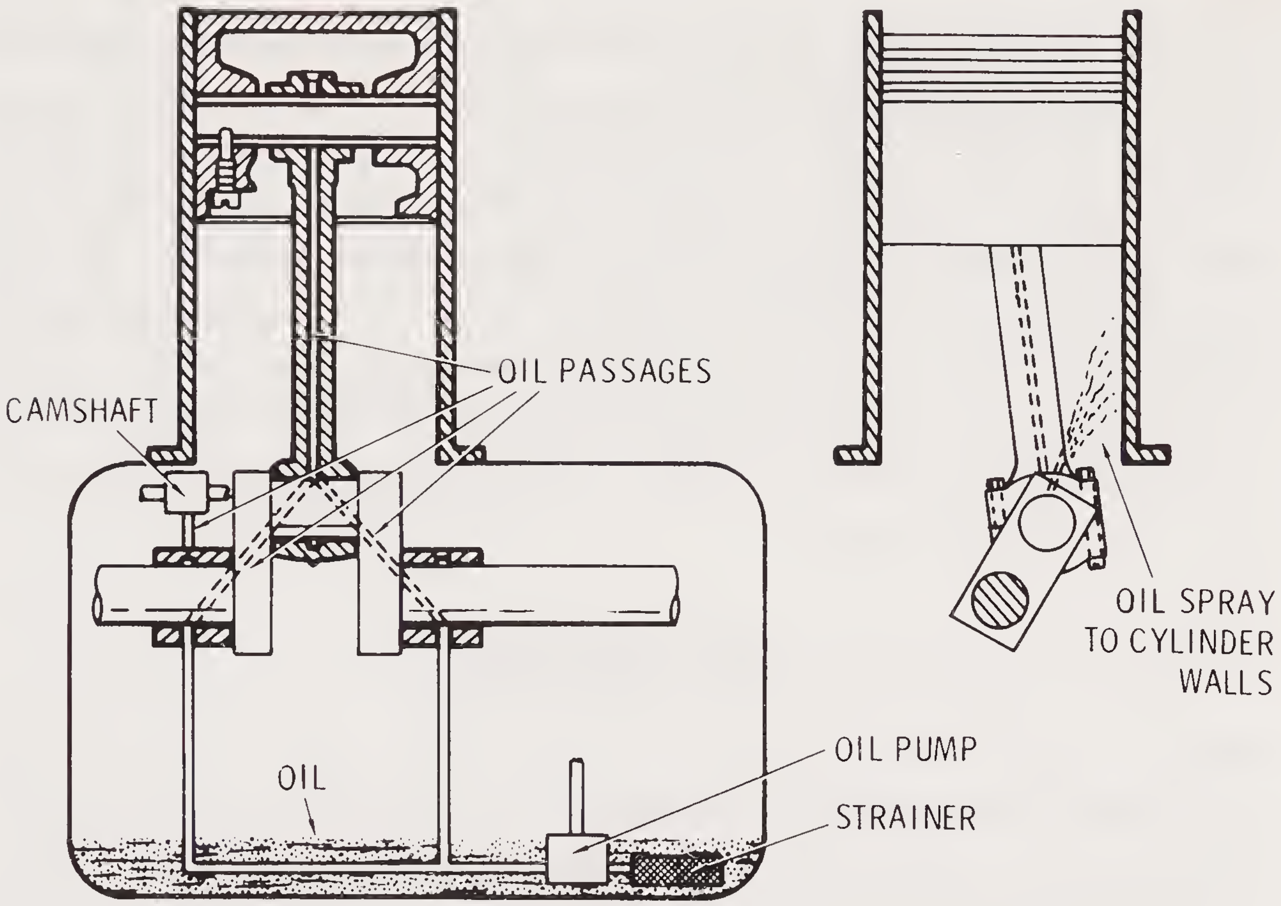



**Fig. 11-3. Cylinder wall lubrication from the full-pressure system.**

the possibility of a complete stoppage of oil flow and consequent damage to the engine. Although some engines are equipped with two strainers, most manufacturers of engines place at least one oil strainer in the lubrication system.

## OIL FILTERS

A second oil purification device is known as the oil filter. The oil filter is placed in the oil line above the pump. It filters the oil and removes most of the impurities, such as sand, dirt and metal particles, that have been picked up by the oil during its circulation through the engine and escaped the strainer.

The filter is usually mounted outside the engine and is connected so that part or all of the oil passes through the engine. Some filters, termed full-flow filters, are designed to handle the full output of the oil circulating pump, and all of the oil passes through them before being distributed to the engine parts. Other types divert only a small amount of the oil each time it is circulated, and after filtering, return it directly to the oil pan.

A typical oil filter is shown schematically in Fig. 11-2. Here

the filtering element consists of an arrangement of screens and a filtering material capable of retaining impurities as the oil is forced through. In time, filters will eventually become blocked with impurities so that oil cannot pass. For this reason, most filters are provided with relief or bypass valves that allow the oil to flow around the filter when the back pressure caused by clogging becomes greater than the tension of the relief-valve spring. Some filters must be replaced when clogged; in others the filter element can be removed and cleaned. See Fig. 11-4 for the complete lubricating system on a V-8 engine.

## OIL GAUGES

Internal combustion engines are normally equipped with an oil gauge and a dipstick, one to indicate the oil pressure in the lubricating system and the other to measure the oil level in the oil pan.

*The oil pressure gauge* is normally mounted on the engine

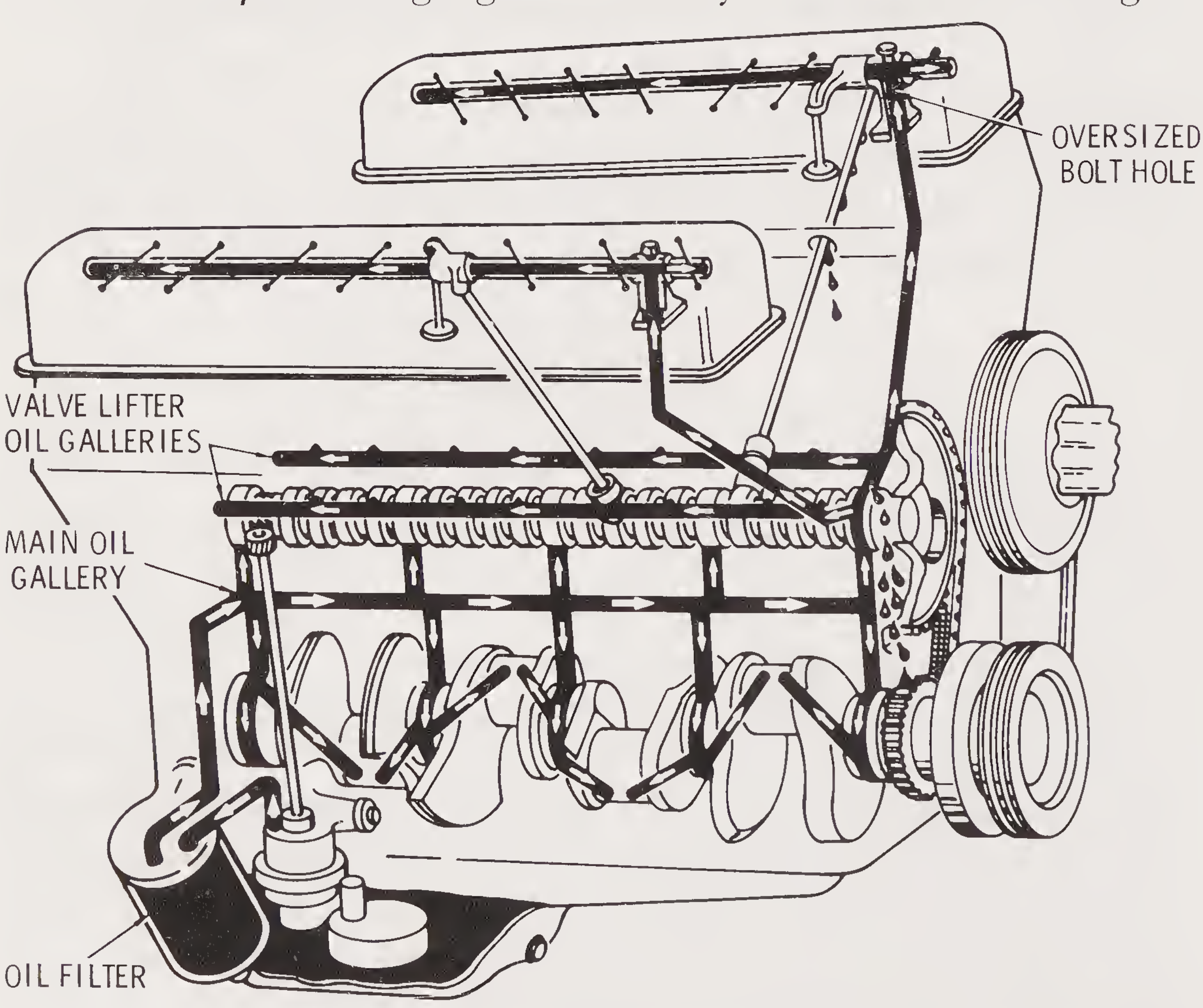



**Fig. 11-4. Full-pressure lubrication as applied to a typical V-8 engine.**

instrument panel and is calibrated in pounds per square inch or some other comparative system to indicate the pressure in the lubrication system. It is connected to an oil line tapped into the main oil supply passage leading from the pump. The pressure of the oil in the system acts on a diaphragm within the gauge, causing a needle to register on a suitable graduated dial.

Oil pressure gauges are of two distinct types and are termed according to their method of operation as:

1. Pressure expansion type.
2. Electrical type.

The *pressure-type gauge* is similar in principle to the well-known water pressure gauge. In the oil pressure expansion type of pressure gauge, however, oil under pressure passes from the engine unit up the connecting tube to the dash unit. As the pressure through the tube builds up, it has a tendency to straighten the C-shaped Bourdon tube in the dash unit and thus move the pointer attached to the free end of the tube.

The *electrical type* consists of a dash unit and an engine unit. The dash unit is connected to the ignition switch and in series with the engine unit. When the ignition switch is turned off, the pointer will rest at the extreme left position. The engine unit contains a diaphragm which is deflected in proportion to the pressure of the oil in the line. Increased oil pressure causes greater deflection of the diaphragm in the engine unit, and therefore a greater amount of current. This increased current is transmitted to the dash unit, causing a corresponding movement of the dash unit and resultant indication of the oil pressure.

If some part of the engine lubricating system becomes clogged, the pressure indicated on the gauge will rise abnormally. Cold and heavy oil will also produce a high pressure reading, whereas very thin oil, under high temperature conditions, will produce a low pressure indication.

The *oil dipstick* is actually a measuring stick, usually of the bayonet type, and consists of a small rod of rectangular cross section which extends into the oil pan through a small hole on the side of the crankcase. It is usually graduated to show the actual oil level, thus giving a reliable indication of the necessity for adding oil to the engine.

## ENGINE OILS

Oils used for engine lubrication are principally derived from petroleum. The petroleum oils are compounded with animal fats, vegetable oils and other ingredients to produce satisfactory oils and greases. Among the several important requirements for a lubricant are:

1. Body or weight.
2. Fluidity or viscosity.
3. Freedom from gumming.
4. Absence of acidity.
5. Stability under temperature changes.
6. Freedom from foreign matter.

The *body of a lubricant* indicates a certain consistency of substance that prevents it being entirely squeezed out from the rubbing surfaces. The particles of the lubricant should adhere to the rubbing surfaces, thus securing effective separation. The body of a lubricant should be such as to prevent a too rapid running off, depending on the rubbing pressure.

*Fluidity of a lubricant* refers to a certain lack of cohesion between its different particles, which reduces the fluid friction. Fluidity, so far as it does not oppose body, is a desirable quality. Excessive fluidity allows the lubricant to run off too quickly, thus causing wear.

A *lubricant that gums* loses its fluidity easily, collects dust and grit, and thus increases friction and wear.

A *lubricant that holds free acid* would attack the bearing surface, destroy its smoothness, increase friction and lead to frequent and costly repairs.

*Stability under temperature changes* is important; lubricants should retain their good qualities, even when used under high or low temperature. They should not evaporate, not be decomposed by heat, nor congeal by cold and should retain their normal body and fluidity over as wide a range of temperatures as possible.

*Foreign matter will increase friction* and clog oil passages, thus causing wear, heating and possible seizing of the rubbing surfaces.

## Viscosity

Viscosity represents the flowing quality of an oil and is determined by noting the number of seconds it requires to pass a certain quantity of the oil at a specified temperature through a standard-size orifice made for the purpose. The *Saybolt universal viscometer* is employed in the United States for this purpose, while the Redwood, Engler and other similar instruments are used extensively in other parts of the world.

It is a well-known fact that heat will thin oil, giving it greater fluidity or lower viscosity. At high temperatures, high-viscosity oils retain a sufficient degree of viscosity. At low temperatures, oils become more viscous. For these conditions, therefore, the lower-viscosity oils are more suitable for lubrication.

## SAE Viscosity Numbers

These numbers constitute a classification of lubricants in terms of viscosity or fluidity, but without reference to any other characteristics or properties. The viscosity numbers are assigned by the *Society of Automotive Engineers* (SAE) in such a way that the higher the SAE number, the more viscous or heavy is the oil. Thus, an SAE 10 engine oil may be recommended for low-temperature use, whereas an SAE 30 oil will be suitable for use in warmer weather.

The added designation of **W**, such as **10W**, indicates that the oil has the added ability to remain fluid or flow at a lower temperature. The manufacturer of an engine usually recommends the viscosity of oil to be used under various conditions.

During cold weather, engine oil selection should be based primarily on easy starting characteristics, which depend on the viscosity of the oil at low temperatures. Fig. 11-5 indicates the temperature range within which each grade can be relied on to provide easy starting and satisfactory lubrication.

When the crankcase is drained and refilled, the oil should be selected not on the basis of the existing temperature at the time of change, but on the anticipated minimum temperature for the period during which the oil is to be used. This is to prevent starting difficulty at each sudden drop in temperature.

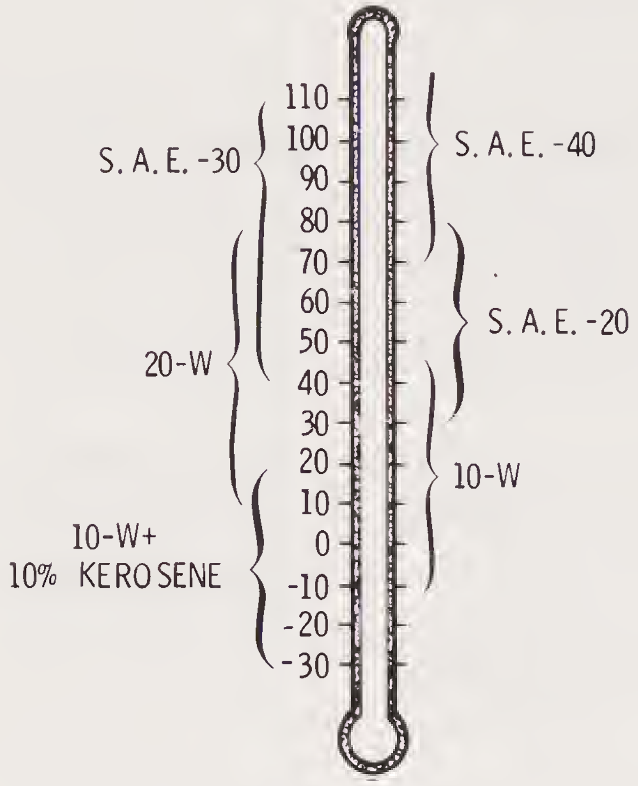



**Fig. 11-5. Temperature range for various SAE oil numbers.**

Most modern oils are *multiviscosity oils.* A multiviscosity oil covers a wide range of temperature applications and is labeled with more than one viscosity number. The lowest number represents the lowest-viscosity oil it can replace in cold temperatures; the highest number represents the highest-viscosity oil it can replace in hot weather. The example below is a very typical multiviscosity oil.

10W–40

The *10* rating tells you this oil can be used in cold-weather conditions where a number 10 oil is specified. The *40* rating tells you this oil can be used in hot weather conditions where a number 40 oil is specified. This oil can, of course, also be used to replace any number 20 or 30 oil.

## Oil Dilution

When lubricating oil becomes diluted with gasoline, it loses its viscosity and some of its lubricating qualities. Excessive use of the choke causes an overly rich mixture to be forced into the cylinders. This excess gasoline remains in a liquid state and drains by the piston rings into the crankcase, where it mixes with the oil. When the engine operates at higher temperatures, this condition is cor-

rected to some extent as the excess gasoline vaporizes in the crankcase and is carried off through the ventilation system.

The presence of gasoline will not lower the oil level but will maintain it or even raise it. The lubricating quality of oil, however, is definitely reduced when diluted with gasoline.

## Corrosion

Practically all present-day engine fuel contains small amounts of sulfur, which in the state in which it is found is harmless. However, on burning, this sulfur forms certain gases, a small portion of which is likely to leak past the piston and rings and, when reacting with water, form very corrosive acids. The more sulfur in the fuel, the greater the danger from this type of corrosion.

This condition cannot be entirely avoided but may be reduced to a minimum by proper care of the engine. As long as the gases and the internal walls of the crankcase are hot, no harm will result, but when an engine is run at low temperatures, moisture will collect and unite with the gases formed by combustion. In this manner acid will be formed and will likely cause serious etching or pitting.

## High-Temperature Operation

High temperature and hard service promote oxidation of lubricating oil. This type of service may cause high-temperature varnish and sludge deposits, stuck rings and scuffing of rings in all types of engines. It may also cause corrosion of some types of bearings.

This condition is aggravated by hard service, particularly in hot weather. Under this condition, the crankcase oil is subjected to relatively high temperatures.

The nature of the fuel may have some influence on the severity of this condition, but its relative influence is less under these high engine temperatures than under start and stop conditions. In engine design especially adequate cooling of oil as well as of pistons, valve guide and seats can minimize the effect on the oil.

## Frequency of Oil Changes

The frequency of oil changes depends on several factors. With reference to automotive engines, the frequency of oil change is usually

determined on a mileage basis. Visual inspection might result in an erroneous interpretation in cases where the filter is still in good condition, in which case the oil would appear fairly clean after many miles even though it might have accumulated harmful acids.

Manufacturers' recommendations for summer in some cases might cause the disposal of oil which is still satisfactory. There are, however, conditions where the roads are extremely dusty and where this recommendation would be more than appropriate. It is better to change the oil too often than not often enough, since keeping the engine oil in good condition is money well spent. Therefore, a manufacturer's recommendation should be strictly adhered to.

CHAPTER 12

# Cooling Systems

All internal combustion engines must be equipped with some type of cooling system because of the great amount of heat generated by combustion of the fuel. The temperature in the combustion chamber during the burning of the fuel is estimated to range from 2700°F. to 3200°F. Accordingly, it must be evident that the intense heat generated within a gas engine cylinder would very quickly overheat the metal within the cylinder to such an extent that it would become red-hot, resulting in burned and warped valves, seized pistons, overheated bearings and a breakdown of the lubricating oil.

To avoid these conditions, means must be provided to carry off some of the heat, enough of it to prevent the temperature of the metal of the cylinder from rising above a predetermined point and low enough to permit satisfactory lubrication and operation. The excess heat is carried off by some form of cooling system.

In this connection, it should be clearly understood that although heat is necessary, as it causes expansion of the charge which acts on the piston head to produce power, a large part of it goes to waste

through the exhaust and in the cooling system. Thus, for example, it is estimated that less than one-third of the heat energy contained in the fuel is converted into useful power, whereas the remaining is either dissipated through the exhaust or is absorbed in the cooling system.

There are four methods of cooling internal combustion engines:

1. By water circulation.
2. By water and oil circulation.
3. By air cooling.
4. By air and oil circulation.

Water cooling is commonly obtained by means of a pump and associated piping, radiator, fan and system of jackets and passageways through the engine within which the water circulates.

High-performance and heavy-duty water-cooled engines may require additional cooling. The water and oil will usually receive extra cooling through an added air-cooled system.

Air-cooled engines employ blades usually incorporated in the flywheel, which acts as a fan to circulate air over the fins cast integrally with the cylinders. Engines of this type are used almost exclusively for small appliances such as lawn mowers and chain saws, and also for lightweight automobile engines.

Air cooling of the oil—to supplement the cylinder cooling—is also used with many air-cooled engines in which the characteristics require additional cooling, or for which space and position limitations make ordinary air cooling alone inadequate.

## WATER-CIRCULATION SYSTEMS

Water is the most widely used coolant for liquid-cooled engines. The main objection to the use of water is that, because of its high freezing point, it cannot be used without additives at temperatures below 32°F.

Cooling of the engine parts is accomplished by keeping the water circulating and in contact with the metal surfaces to be cooled. The pump draws the water from the bottom of the radiator, forces it through the jackets and passages, and ejects it into a tank on top of the radiator. See Fig. 12-1.

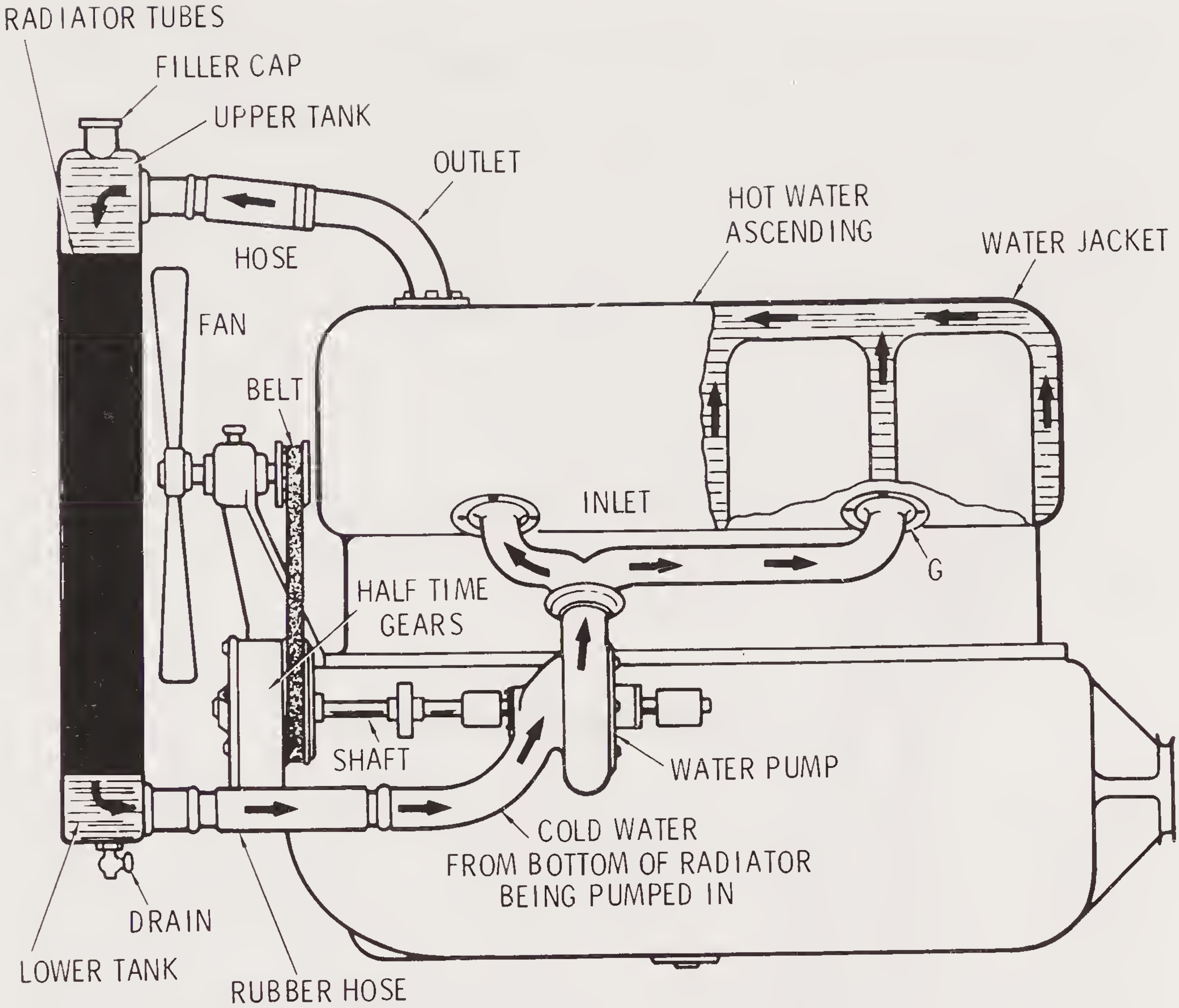



**Fig. 12-1. Elementary diagram showing a water-circulation cooling system.**

The water passes through a set of tubes to the bottom of the radiator and again is circulated through the engine by pump action. A fan, driven by the engine, draws air over the outside of the tubes in the radiator and cools the water as it flows downward.

It should be noted that the water is pumped through the radiator from the top down. The reason for this direction of flow is that the thermosiphon action aids the pump to circulate the water. This simply means that as the water is heated in the jackets of the engine, it expands slightly and as a result becomes lighter and flows upward to the top of the engine. As cooling then takes place in the radiator tubes, the water contracts, becomes heavier and sinks to the bottom. This desirable action cannot take place if the water level is allowed to become too low.

The fan that is used to cool the water in the radiator may be a

constant-speed fan (one that produces a volume of air directly proportionate to the engine speed), or a fan that will vary the quantity of cooling air it produces in accordance with a formulated need. Actual need for fan-created air varies with the forward speed of the vehicle; a slow-moving (or stationary) vehicle has little or no motion-created airflow; but a faster-moving vehicle generates a proportionately increased airflow which, at some point, becomes greater than the airflow created by a fan. Furthermore, revolving a fan consumes motor power, and a decrease of fan energy in relation to the decrease of its need obviously saves motive power.

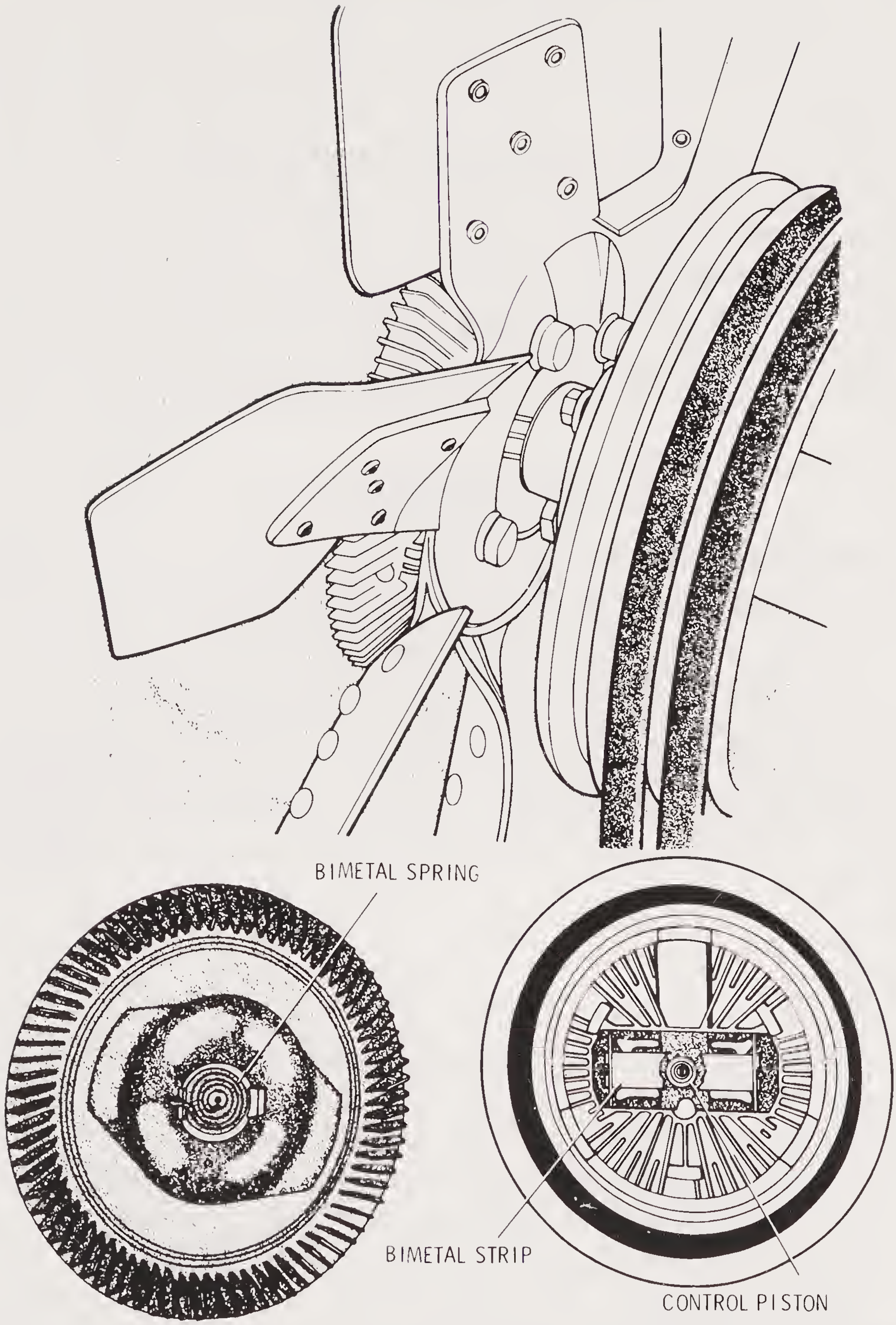
There are two ways to decrease fan energy (motor-power consumption). One is to vary the rpm of the fan; the other, to vary the pitch (blowing angle) of the fan blades.

## VARIABLE-SPEED FANS

Fan rpm is varied by means of a fluid coupling (fan clutch) in the fan shaft. Torque-carrying capacity of the coupling (and, consequently, the percentage of fan-pulley rpm transmitted through it to the fan) depends upon the amount of fluid (generally silicone oil) between the two coupling plates; the greater the amount of fluid, the greater the torque will be. Fluid is stored in a reservoir in the coupling body and is pumped between the plates or bled back into the reservoir by operation of a control piston at the coupling axis. This piston is moved by the expansion or contraction of a bimetal thermostat which may be either a flat-spring or a coiled-spring type, and which is located on the front of the coupling (between the fan and radiator), where it will be affected by the heat of the air passing through the radiator. See Fig. 12-2.

## VARIABLE-PITCH FLEX FAN

This type of fan has flexible blades which increase or decrease the blade "scoop" and thus vary the quantity of air the fan will blow at any given rpm. Since the blades are flexible, they will tend to "flatten out" and lose their scooping action when operated at higher engine speeds.




Variable-speed with coiled bimetal thermostat spring.

Variable-speed with flat bimetal thermostat spring.

**Fig. 12-2. Typical variable-speed fan assembly.**

## ENGINE WATER JACKET

Water jackets in internal combustion engines consist of an outer casing surrounding the cylinders. The circulating water passes through the space between the casing and the cylinders. In modern construction, the jacket is so arranged that in the block and cylinder head, water completely surrounds the cylinder bores, the valve seats and the valve stems.

Carefully engineered water passages in the head aid in regulating the water flow and help to maintain uniform temperature throughout the block. Water completely surrounds the combustion chamber and spark plug bosses in the cylinder head.

## RADIATORS

By definition, a radiator is an assemblage of numerous very small passages of circular or rectangular forms constructed of thin metal to form the cooling surface for the circulating water.

The radiator must be strong enough to withstand vibration and the walls thin enough to reduce the weight to a minimum and offer the least possible resistance to the transfer of heat from the water circulating within its passages to the air current passing over the exterior or cooling surface. Radiators are built in two general classes, namely:

1. Cellular.
2. Tubular.

The *tubular radiator* cores or cooling surfaces consist of a large number of vertical water tubes and numerous horizontal air fins around the tubes. Water passages in the tubes are narrow, and the tubes are made of thin metal. The core divides the coolant into very thin columns or ribbons, thus exposing a large radiating surface to the volume of water to be cooled. This is the most popular type.

*Cellular radiator* construction consists of nesting individually formed hexagonal tubes, cut to length according to the depth of the core from front to back, and dipping both surfaces, front and back, in a bath of solder to make a complete unit. Such construction resembles a honeycomb made by bees.

If such cells are hexagonal in appearance, the radiator is called a cellular honeycomb. The water passes in channels between the tubes and the air passes through the cells in this type of core.

## WATER-CIRCULATING PUMP

All modern cooling systems have pumps to obtain forced water circulation. The water pump is usually of the centrifugal type and has an impeller with blades to force the water outward as the impeller rotates. The pump and fan are usually driven from a common V-belt, which is driven by a pulley at the front end of the crankshaft. See Fig. 12-3.

Advantages of the centrifugal-type pump are that it circulates a great quantity of water for its size, is not easily clogged by small particles of dirt and is simple in construction. Another advantage is that it permits limited circulation by thermosiphon action even if the engine is not running. See Fig. 12-4.

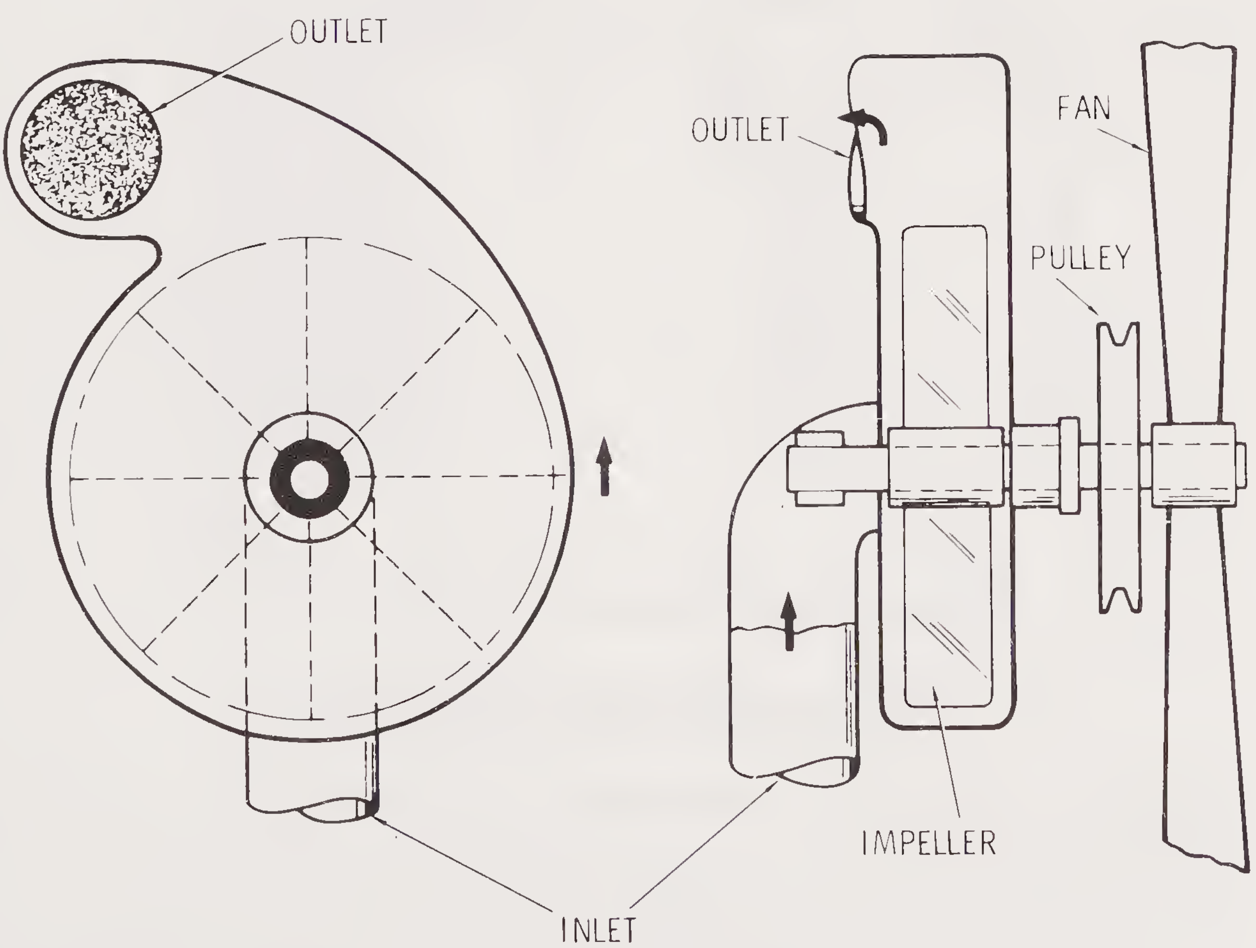



**Fig. 12-3. The elementary centrifugal water pump.**

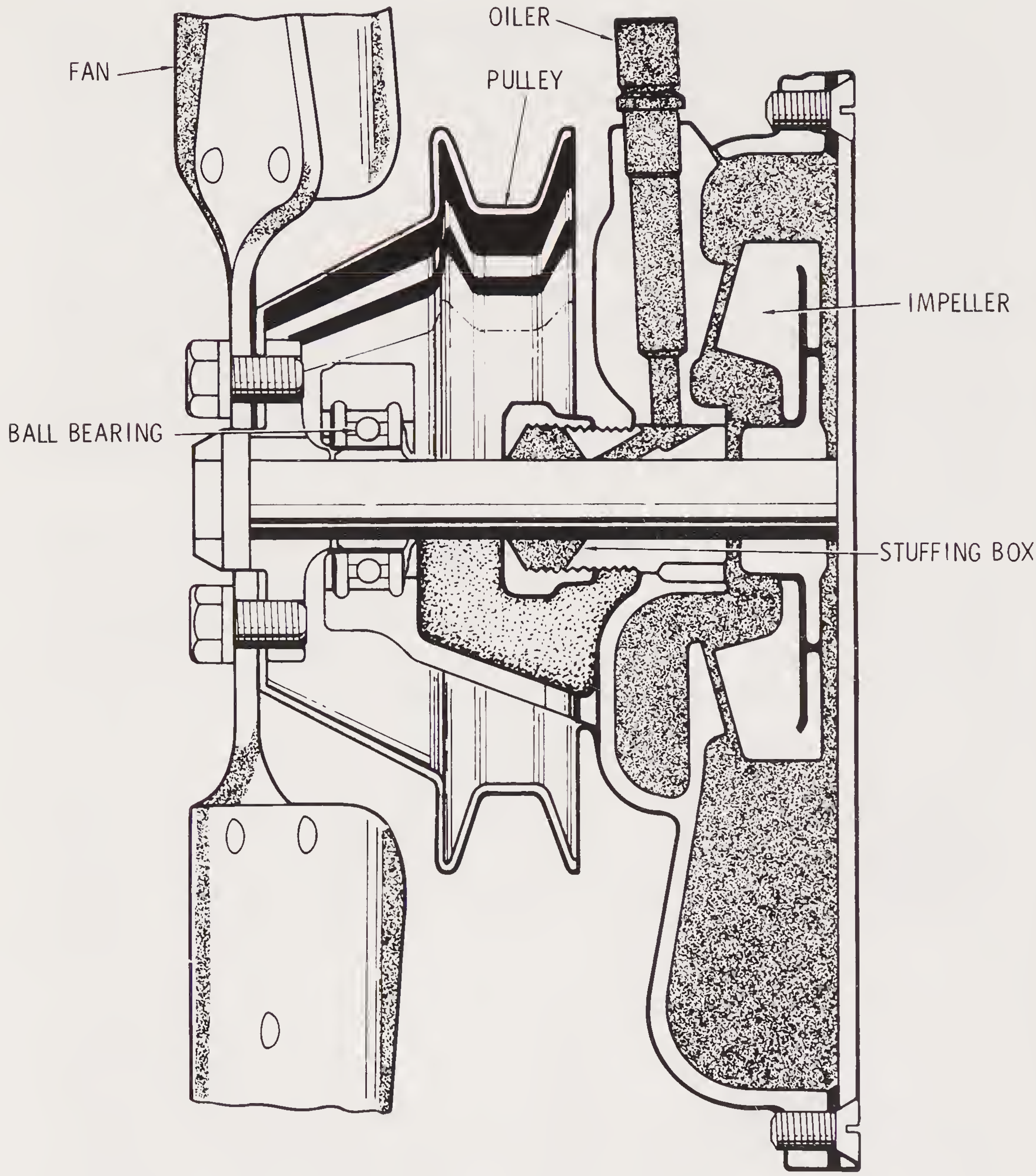



**Fig. 12-4. Typical water pump and fan assembly.**

## TEMPERATURE CONTROL

Radiators are provided with sufficient cooling surface to cool the engine adequately even during hot weather at normal load. At starting and during cold weather, however, some method must be found to regulate the temperature, since if the engine remains too cool, unsatisfactory operation will result.

To keep the engine as close as possible to a predetermined

temperature, a thermostat is inserted between the water jacket and the radiator, usually at the housing at the cylinder head water outlet as shown in Fig. 12-5. The function of the thermostat is to regulate the engine temperature by automatically controlling the amount of water from the engine block to the radiator core.

The thermostat is merely a heat-operated unit that controls a valve between the water jacket and the radiator. Thus, when the engine is cold, the thermostat valve remains closed, and the water is recirculated through the water jacket without entering the radiator. As the engine warms up, the valve slowly opens and some water begins to flow through the radiator, where it is cooled.

A typical thermostat consists of a flexible metal bellows attached to a valve. The sealed bellows, which is expandable, may fill with

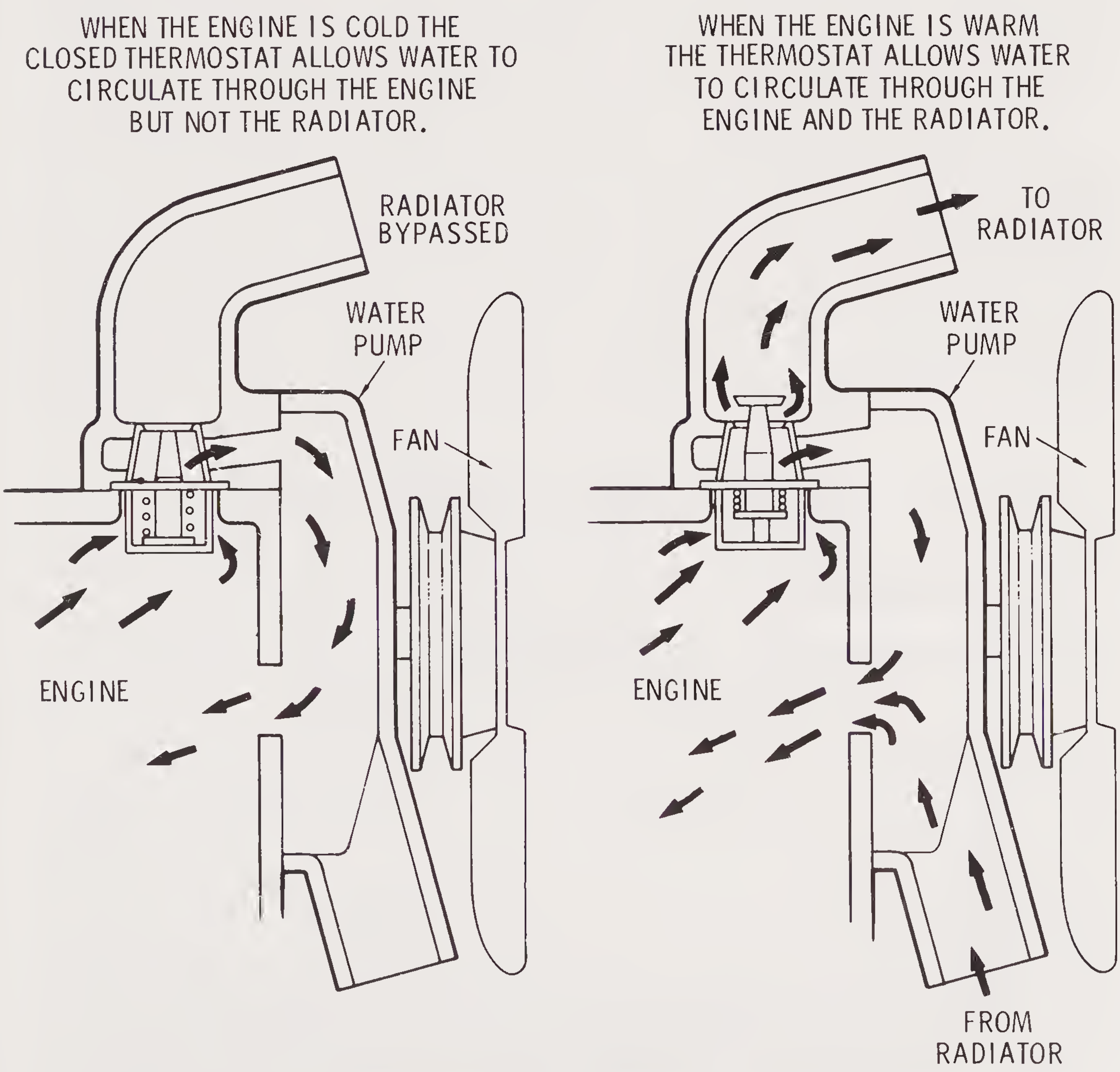



**Fig. 12-5. General location and operating principle of a thermostat.**

a highly volatile liquid. When the liquid is cold, the bellows chamber is contracted and the valve is closed. When heated, the liquid is vaporized and expands. As the chamber expands, the valve opens to permit water circulation between the engine jackets and the radiator.

Other thermostat types include a sealed copper bellows containing only air. Some of the newer types are filled with wax. Another is bimetallic and depends for its operation on the difference in coefficient of expansion of the two metals.

## RADIATOR PRESSURE CAP

Some engine cooling systems are sealed by a pressure-type radiator filler cap which causes the system to operate at higher than atmospheric pressure. This higher pressure raises the boiling point of the coolant and increases the cooling efficiency of the radiator.

The pressure radiator cap contains two spring-loaded valves which seal the system. See Fig. 12-6. The larger of the two valves is a pressure valve, while the smaller valve is a vacuum valve. The pressure valve acts as a safety valve to relieve extra pressure within the system. The vacuum valve opens only when the pressure within the cooling systems drops below the outside air pressure as the engine cools off. Higher outside pressure then forces the vacuum

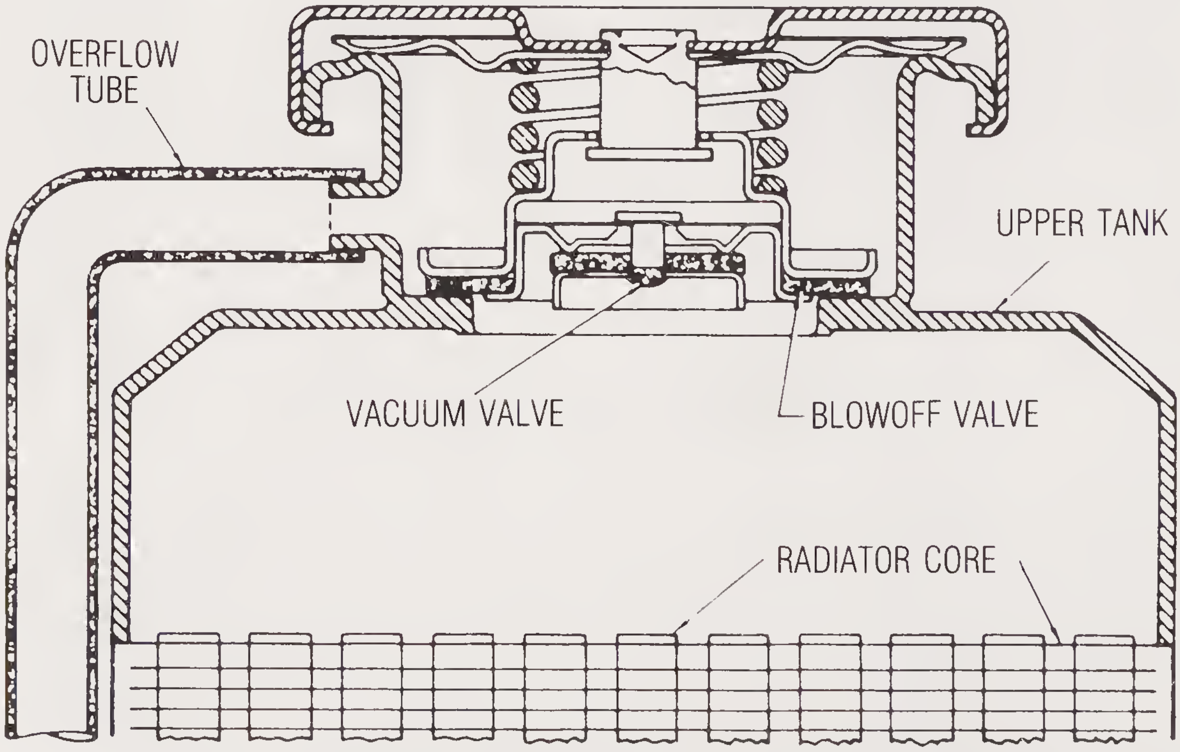



**Fig. 12-6. Typical pressure-type radiator cap assembly.**

valve to open, permitting air to enter the system by way of the overflow tube.

Most modern systems are closed systems. In a closed system an overflow bottle known as a *catch can* is attached to the overflow tube. As the system heats up and the coolant expands, some fluid forces the cap open and flows into the catch can. As the system cools off and the coolant in the radiator contracts, fluid is drawn back into the radiator. With this system, the radiator is always kept completely full and the fluid level can be checked, hot or cold, at the overflow bottle without removing the radiator cap.

## ANTIFREEZE SOLUTIONS

When an engine is operated where the atmospheric temperature is below 32°F., an antifreeze solution must be added to the cooling water. If a container is filled with water and allowed to freeze, it will burst. The same thing will happen to a cylinder block or to a radiator unless an antifreeze solution is added to prevent freezing.

There are several antifreeze solutions available that are satisfactory for engine cooling systems. Among these are *methyl alcohol*, *ethyl alcohol*, *glycerin*, and *ethylene glycol*. The first two are the cheapest and provide adequate protection when used in sufficient quantities. The main objection to their use is that they boil and evaporate if normal operating temperatures are exceeded.

Glycerin offers the same degree of protection as alcohol and does not evaporate in use because of its high boiling point. Ethylene glycol, the most popular antifreeze compound, has an extremely high boiling point, does not evaporate in use, is noncorrosive, has no odor and furnishes complete protection when used in the proper amount.

When using ethylene glycol, it is necessary to clean the entire cooling system before putting in the antifreeze solution. It is also advisable to tighten and replace all hose connections. It is important that the cylinder head gasket be kept tight to prevent leakage.

If there are leaks in the system, they should be located and stopped. If evaporation occurs with the use of ethylene glycol, it is only necessary to add water to the solution. The cooling system should, however, be watched closely for leaks and should be tested when additional water is required.

The freezing point of an antifreeze solution may be determined by using a hydrometer. When testing the solution, however, it should be tested at the temperature for which the hydrometer is calibrated, and the correct hydrometer for the solution should be employed.

### Precautions

Solutions containing salt, calcium chloride, soda, sugar or mineral oils such as kerosene or engine oil should never be used in the cooling system as they either clog the water passages or damage the hose connections and other parts.

### Rust Inhibitors

The use of inhibitors or rust preventors will reduce or prevent corrosion and the formation of scale in the cooling system. Inhibitors are not cleaners and do not remove rust or scale already formed; they are added to the cooling liquid to prevent further rust or corrosion.

The logical time for flushing and introducing the inhibitor is when antifreeze is installed. Care must be taken, however, in the selection of an inhibitor as some of them contain strong acids or caustics that will react with the metal of the radiator core, eating holes through the metal and causing the radiator to leak.

## OIL COOLING SYSTEMS

High-performance (sports and racing) cars may be so streamlined that the space provided for a radiator is limited and the resulting water-circulating system is inadequate for the cooling needed. To offset this design disadvantage, additional engine cooling is accomplished by cooling of the engine oil. This is done in different ways.

The simplest method is to provide an oversized oil pan having external fins exposed to the air so that heat carried by the oil circulating through the engine will be more readily dissipated to the atmosphere. Oil pan radiation area is carefully calculated to compensate for the reduction of water-cooling capacity. Another method is to circulate the oil through an oil radiator, known as an

oil cooler, in which it can be cooled prior to returning to its normal course through the engine. The oil cooler can utilize forced air or may be installed in the coolant system, using fluid from the radiator.

## AIR COOLING SYSTEMS

An air cooling system, as the name implies, consists in forcing air under pressure, over special cooling flanges which are cast integrally with the cylinders. The circulating air fan is often mounted on the flywheel.

In air-cooled engines, the cooling flanges or metal fins absorb the heat of fuel combustion and diffuse it in the rush of air supplied by the fan. It should be noted, however, that although the cylinder fins increase the effective radiating surface of the cylinder to a considerable extent, larger-horsepower engines are almost exclusively water-cooled because air does not absorb heat as readily as does water.

There are several physical characteristics peculiar to automotive engines of the air-cooled type. The cylinder head and barrel are heavily finned for strength and adequate cooling. Air deflectors or baffles direct the airflow to the cylinders and increase its velocity. A streamlined cowling or shroud surrounds the engine as another means of contolling the airflow; finally, a cooling fan is usually mounted on the engine to direct high-speed air to the cylinders. The obvious exception is motorcycles, in which the unobstructed flow of air caused by forward motion is utilized.

## AIR- AND OIL-CIRCULATING SYSTEMS

As with a water-circulating system, some air-cooled designs do not permit adequate cooling, and additional cooling of the engine oil is required to maintain proper engine operating temperatures and oil lubricating qualities. An oil cooler, such as described for a water- and oil-circulating system, above, is employed. This is located within the engine shroud so that part of the air being blown past the engine cooling fins will be blown past the oil cooler as well. A conveniently placed bimetal thermostat is generally used to adjust the air intake opening into the shroud so that total cooling effect can be controlled for all conditions of engine operation.

This combined air- and oil-cooling system is currently used for car engines, and even for some bus and van engines. The system permits enclosure of the engine within the vehicle "shell" without visible protrusions of engine parts in order to obtain adequate air cooling.

CHAPTER 13

# Fuel Systems

Two types of gas-engine fuel systems are in use:

1. A carburetor system.
2. A fuel-injection system.

Both systems require several basic parts (Fig. 13-1): a *storage tank* for the fuel; an *intake manifold* to distribute an explosive mixture of fuel and air to the cylinders; an *exhaust manifold* to dispose of the mixture residue after its use in the cylinders; and *tubing* to convey fuel from one system part to another. Both systems also incorporate a *muffler* to silence the exhaust, a *fuel gauge* to register the amount of fuel remaining in the tank, some type of *fuel filter* to strain out impurities, and an *air cleaner* that accomplishes a like purpose. Other parts of the two systems differ and require separate discussions. First, we will discuss all the components of a carburetor system.

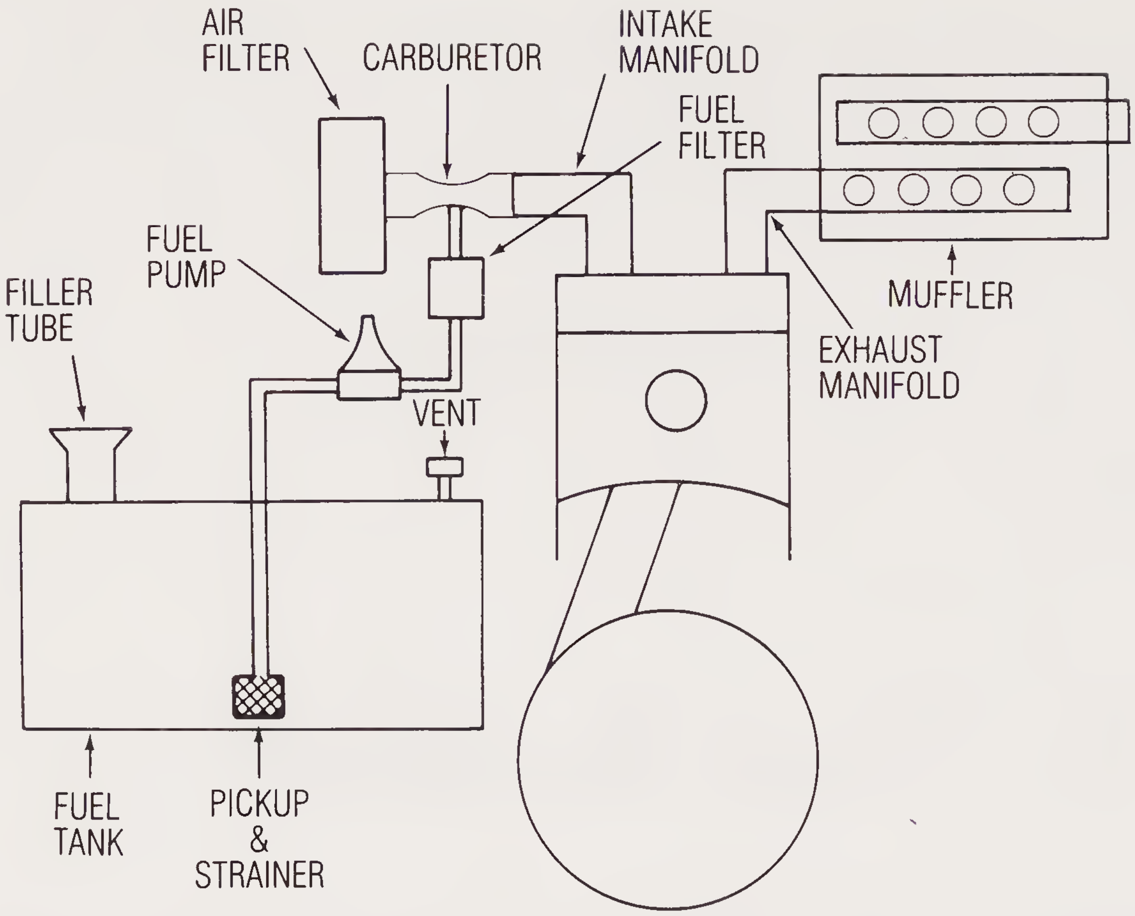



**Fig. 13-1. Elementary diagram showing the essential parts of a fuel system.**

## CARBURETOR FUEL SYSTEM

This (most widely used) system employs a *carburetor* of some type to meter fuel as needed and atomize it into an airstream for mixing with the air. Mixing is begun in the carburetor (as the fuel spray enters the airstream), but is completed in the intake manifold through which the mixture is swirled on its way to the cylinders. Some very simple carburetors do no more than spray an amount of fuel determined by the throttle position into an airstream, the volume of which is principally controlled by engine speed. Other, more sophisticated models are designed to meter the fuel as needed for a variety of conditions (such as at starting, when accelerating or under load, etc.). Carburetor functions and types are discussed in Chapter 14.

All of the components previously mentioned are needed with a carburetor system. In addition, most industrial and automotive applications require a *fuel pump* to deliver fuel from the tank to the carburetor. Some small engines, however, use either a *gravity-flow system* or a *pressure-feed system* in place of a fuel pump.

### Gravity-Flow System

In this type of system there are *no* pumping components in the fuel line between the tank and carburetor. The tank is simply exposed (by a vent hole) to atmospheric pressure, and fuel flows by gravity to the carburetor. The fuel level in the tank must, at all times, be higher than in the carburetor.

### Pressure-Feed Systems

In the pressure-feed system a special air-pressure tube, between the crankcase and the fuel tank, serves to feed the fuel to the carburetor. *In operation*, pressure built up in the crankcase, when the piston is on its downward stroke, is transferred to the gasoline tank by way of a *check valve* and tube. At periods of high crankcase pressure, the check valve is forced off its seat to permit transfer of pressure to the fuel tank. During low-pressure periods the valve closes, thus preventing pressure loss back into the crankcase. An airtight fuel-tank cap is used so that the tank is *not* subject to atmospheric pressure—only to the pressures created within the crankcase. See Fig. 13-2.

## TYPES OF FUEL PUMPS

Industrial and automotive engines having carburetors equipped with a fuel pump are designed to supply fuel to the carburetor under all operating conditions. The pump must also maintain sufficient pressure in the fuel line between the pump and carburetor to keep the fuel from boiling and to prevent vapor lock. Two types of pumps are currently in use: mechanically actuated and electrically operated.

### Mechanically Actuated Fuel Pumps

There are two types of mechanically actuated pumps:

1. Single diaphragm.
2. Double diaphragm.

The single-diaphragm type is ordinarily used on gasoline en-

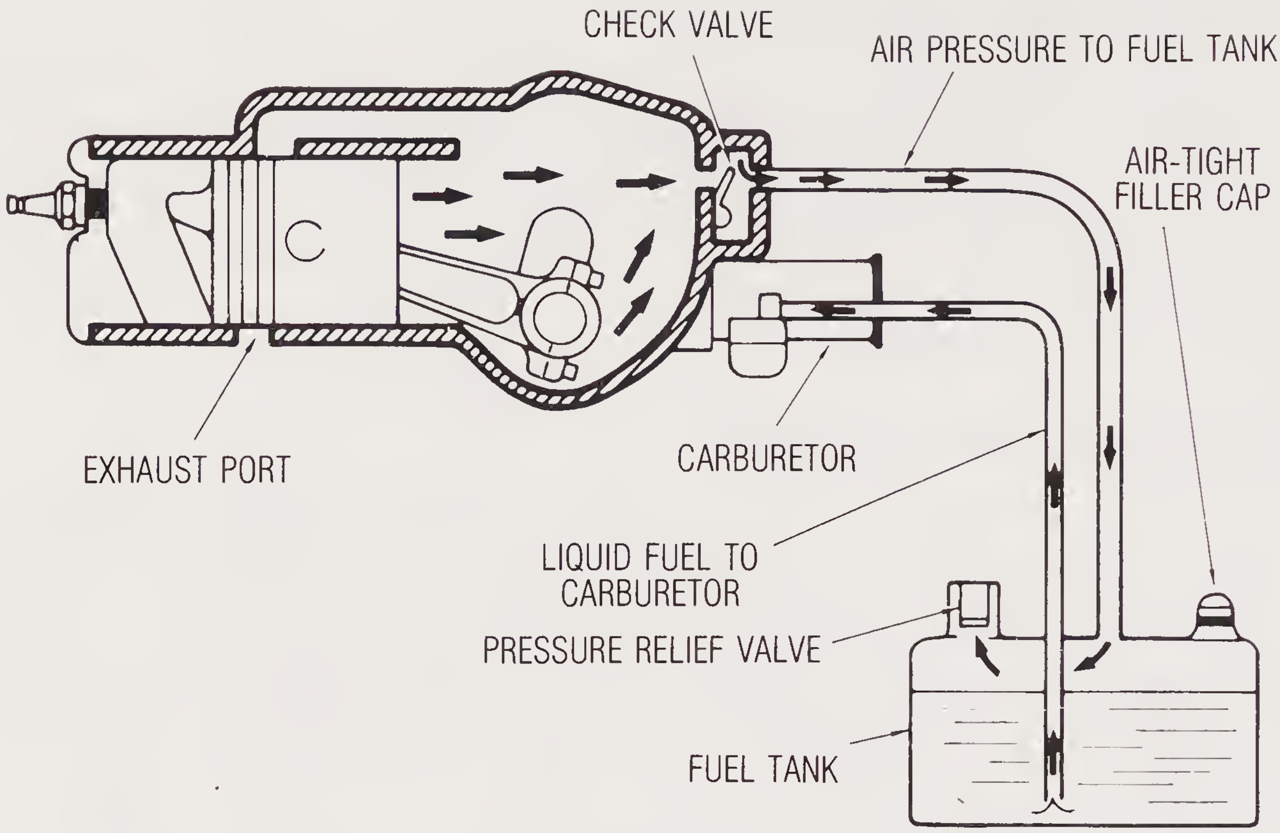



**Fig. 13-2. Pressure-type fuel system as employed on a two-stroke-cycle engine.**

gines. With reference to Fig. 13-3, illustrating a typical single-diaphragm pump, the rotation of an eccentric on the camshaft actuates the rocker arm, which pulls the pump lever and diaphragm spring. This creates a pressure differential in the pump chamber which permits gasoline from the tank to be forced through the filter and inlet valve into the chamber.

The diaphragm is moved up on its return stroke by the pressure on the diaphragm spring, and gasoline is forced through the outlet valve to the carburetor. When the carburetor bowl is filled, a back pressure is created in the fuel pump chamber, holding the diaphragm down against the pressure of the spring. It maintains this position until the carburetor requires additional fuel and the needle valve opens.

The rocker arm and the pump lever are in two pieces, which operate as a single part when the diaphragm is moving up and down. When fuel is not required, however, and the lower part of the rocker arm is held down at one end of the diaphragm pull rod, only the upper part operates in the normal way. This is possible because the rocker arm operates against the lower part only in the downward direction.

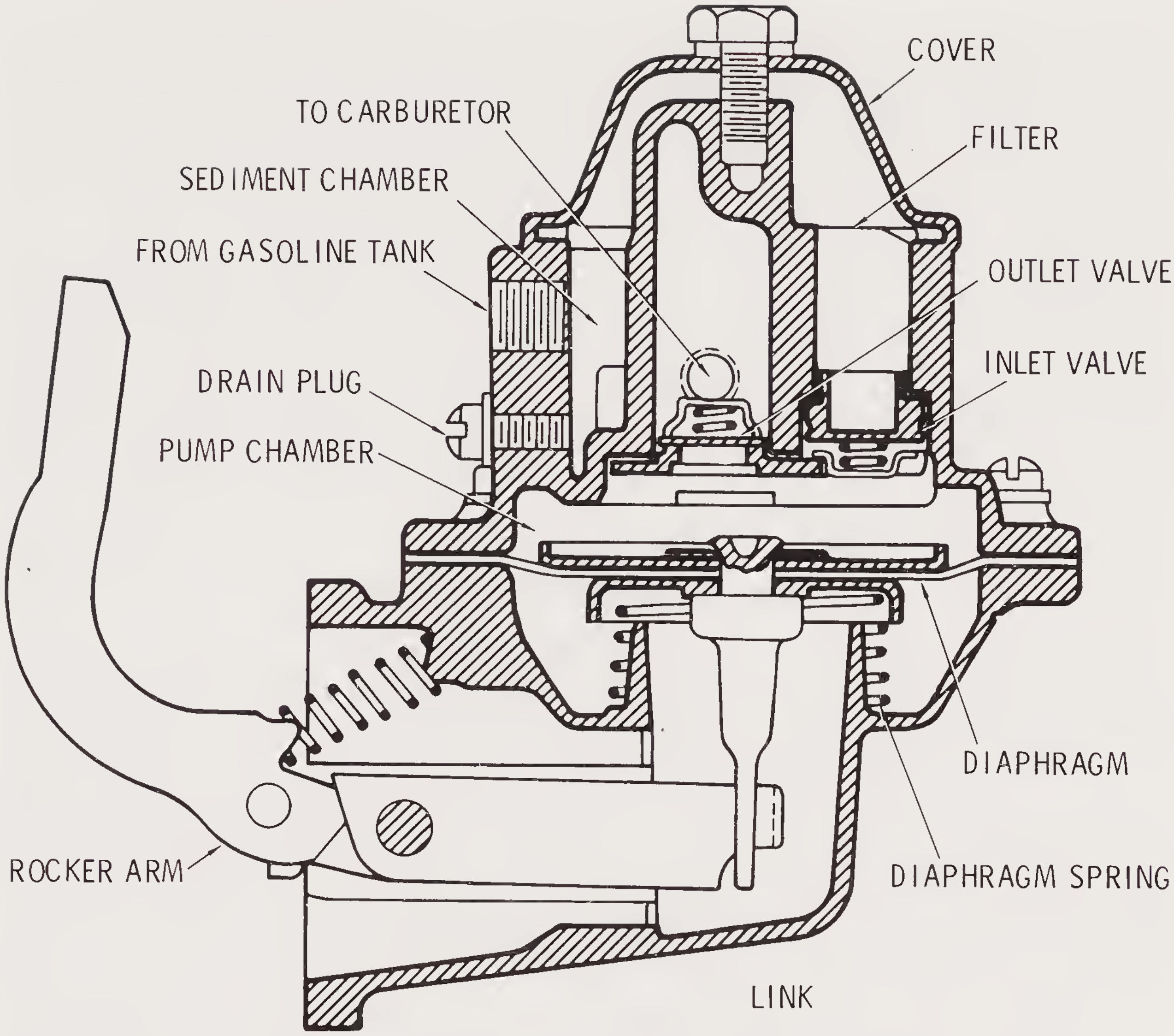



**Fig. 13-3. Sectional view of a typical fuel pump.**

In the event that the fuel supply in the gasoline tank becomes exhausted, the fuel pump will require no priming when the supply is replenished, as a few strokes of the pump at cranking speed will draw fuel from the tank to the carburetor.

The double-diaphragm pump, employed on some older automotive engines, has a vacuum booster section to provide windshield-wiper operation. It is designed on the same principles as the single-diaphragm type. The booster section operates the windshield wiper only and has nothing to do with the fuel system, except that it is operated by the fuel pump rocker arm.

## Electrically Operated Fuel Pumps

From the standpoint of automotive engine design, a mechanically actuated fuel pump has the disadvantage that it must be positioned where the camshaft or crankshaft can actuate the pump rocker arm.

For an engine crowded with accessories, this limitation can pose severe design problems. On the other hand, an electrically operated pump can be located wherever it is convenient to run the fuel line. In some vehicle models the electric pump is positioned within the fuel tank.

One type of electric pump consists of a single diaphragm actuated by a spring-loaded battery-operated solenoid with breaker points to interrupt the current flow. Fig. 13-4 illustrates a typical pump of this type. Whenever the vehicle ignition switch is on, current passing through the closed breaker points energizes the solenoid magnet, which thereupon retracts the plunger and moves the diaphragm (connected to the plunger) outward to draw fuel into the pump body. At the end of this outward stroke the plunger moves a rocker arm which, in turn, opens the points to break the circuit. This allows the spring to return the plunger to starting position, thus moving the diaphragm inward to force the fuel from the pump body into the outlet line and, at the same time, reclosing the points so that the cycle can be repeated. Spring-loaded, one-way valves at the inlet and outlet sides of the pump body keep the fuel moving forward.

Another type is a motor-driven turbine pump. The small d.c. motor and integral pump blade are fully enclosed in one housing, and must be replaced as a unit if defective.

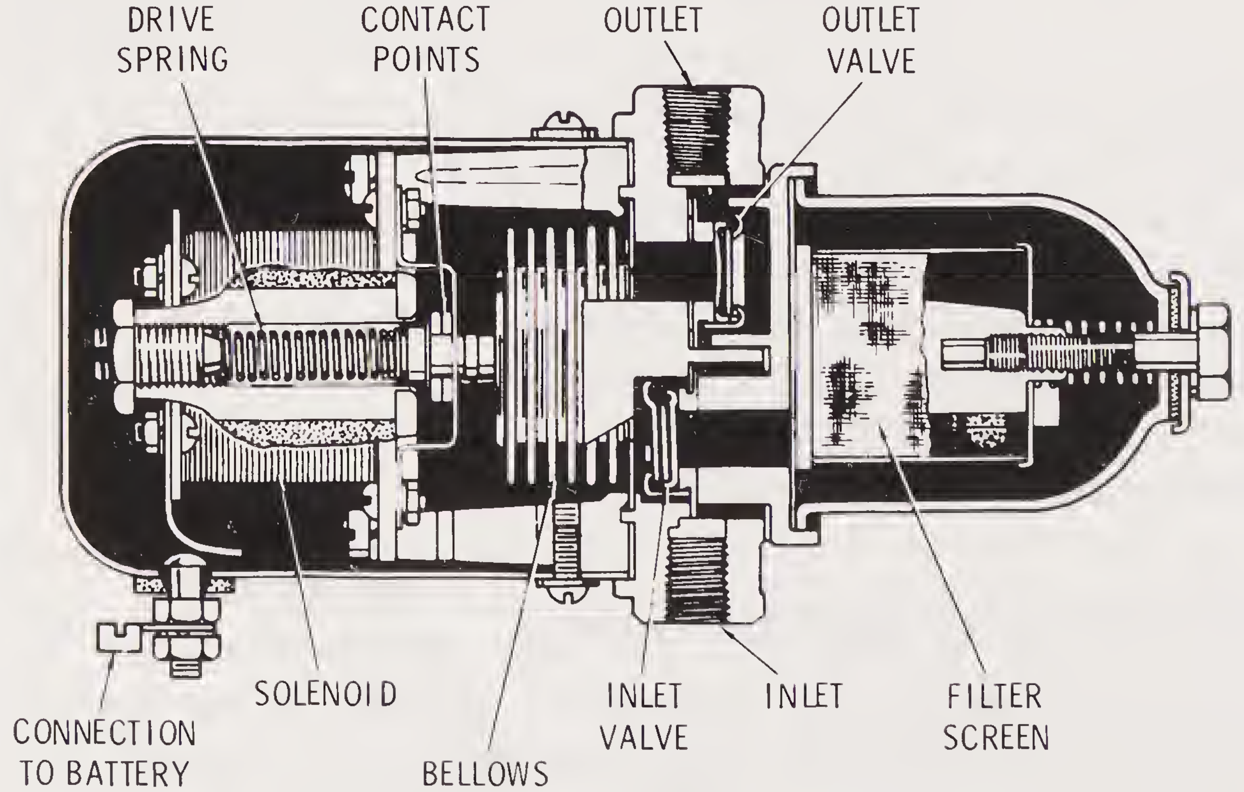



**Fig. 13-4. A typical solenoid-operated fuel pump.**

Both types of electric pumps may be powered, when the engine is running, through a switch controlled by the engine oil pressure. For engine starting, current is supplied through the ignition switch (in cranking position) or through the starter solenoid, but this circuit is cut after the ignition switch is turned to the run position. Dependence of the fuel pump for current on the oil pressure assures that the fuel supply to the carburetor will be cut off should engine oil pressure drop below a predetermined psi. Some pumps are designed for in-tank mounting and may include an attached fuel gauge sending unit. See Fig. 13-5.

## FUEL FILTER

The purpose of the fuel filter is to remove dirt and foreign matter from the gasoline. It may be located at any point between the fuel tank and the carburetor, but on automobiles is usually placed between the fuel pump and the carburetor.

The filter is often an integral part of the pump, especially if it is of the sediment bowl type. In a filter of this type, fuel enters the glass bowl and passes up through the filter screen before flowing through the outlet. Any water and solid matter caught by the screen falls to the bottom of the bowl, from which it can be removed.

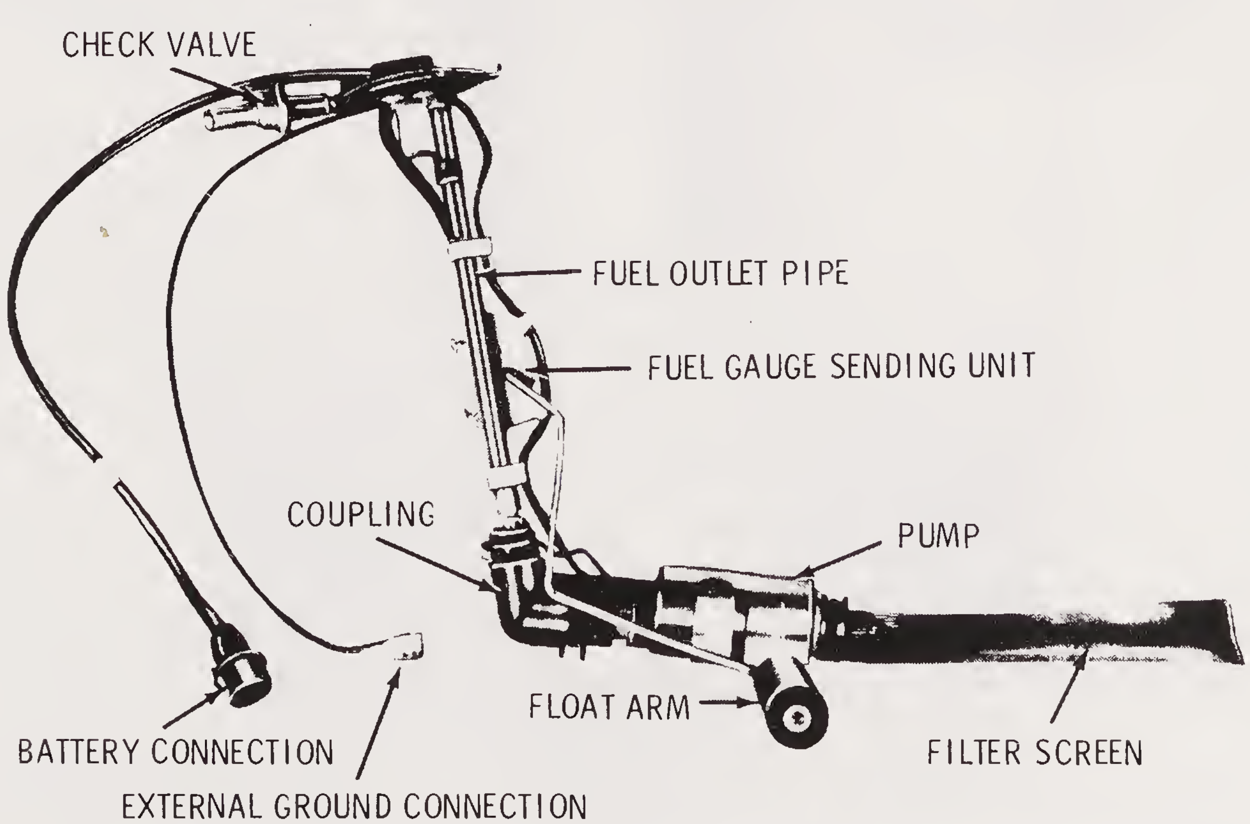



**Fig. 13-5. Electric fuel pump and gauge tank-unit assembly.**

Another type of fuel filter consists of a series of laminated discs placed within a bowl-type enclosure, the bowl acting as a settling chamber for the fuel and enclosing the discs or strainers (Fig. 13-6). In this type, fuel enters the filter at the top inlet connection and flows down between the discs and then up through a central passage to the outlet connection at the top of the bowl. Dirt and foreign particles cannot pass between the discs and are deposited at the outer rim.

Still another type consists simply of a material (screen), of which modern technology has created many. This is leakproof and attached like a sock over the inlet end of the fuel line inside the tank.

Still another type of filter consists of a two-part casing inside

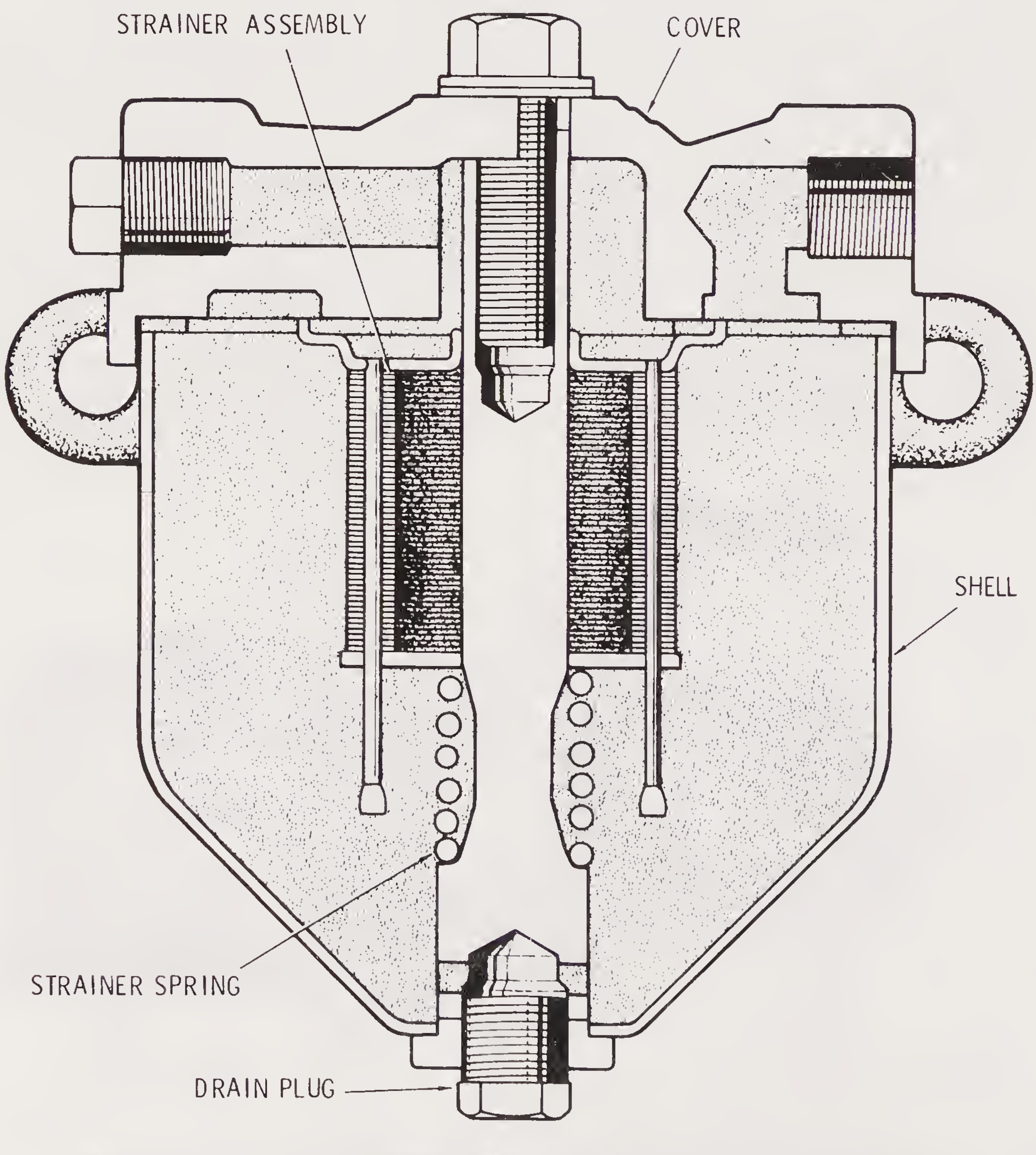



**Fig. 13-6. Typical fuel filter showing laminated disc assembly.**

of which is a throwaway paper filter element (which must be replaced per manufacturer's specifications). See Fig. 13-7.

Other popular types of fuel filters are designed to be disposable. They are usually made of special filter paper or porous synthetic stone. Some are spliced into the fuel line, while others are mounted inside the carburetor inlet.

## AIR CLEANER

The purpose of the air cleaner is to remove dust and other air impurities so that clean air is delivered to the engine cylinders. They are usually installed at the carburetor air intake. There are two types of air cleaners, classified as *wet type* and *dry type*.

The *wet type*, also termed *oil-bath cleaner*, consists of a main body, a unit filled with metallic wire gauze and a cover plate (Fig. 13-8). Air entering the cleaner has to pass through small ports at

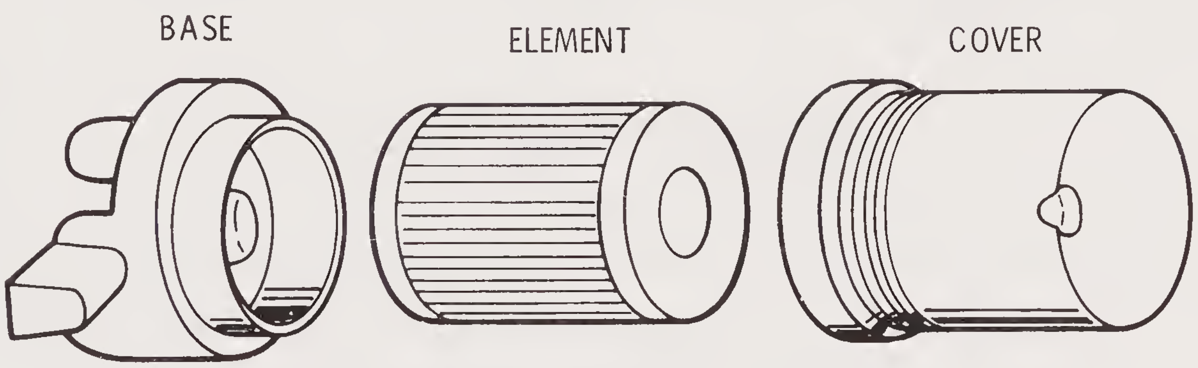



**Fig. 13-7. Paper element fuel filter.**

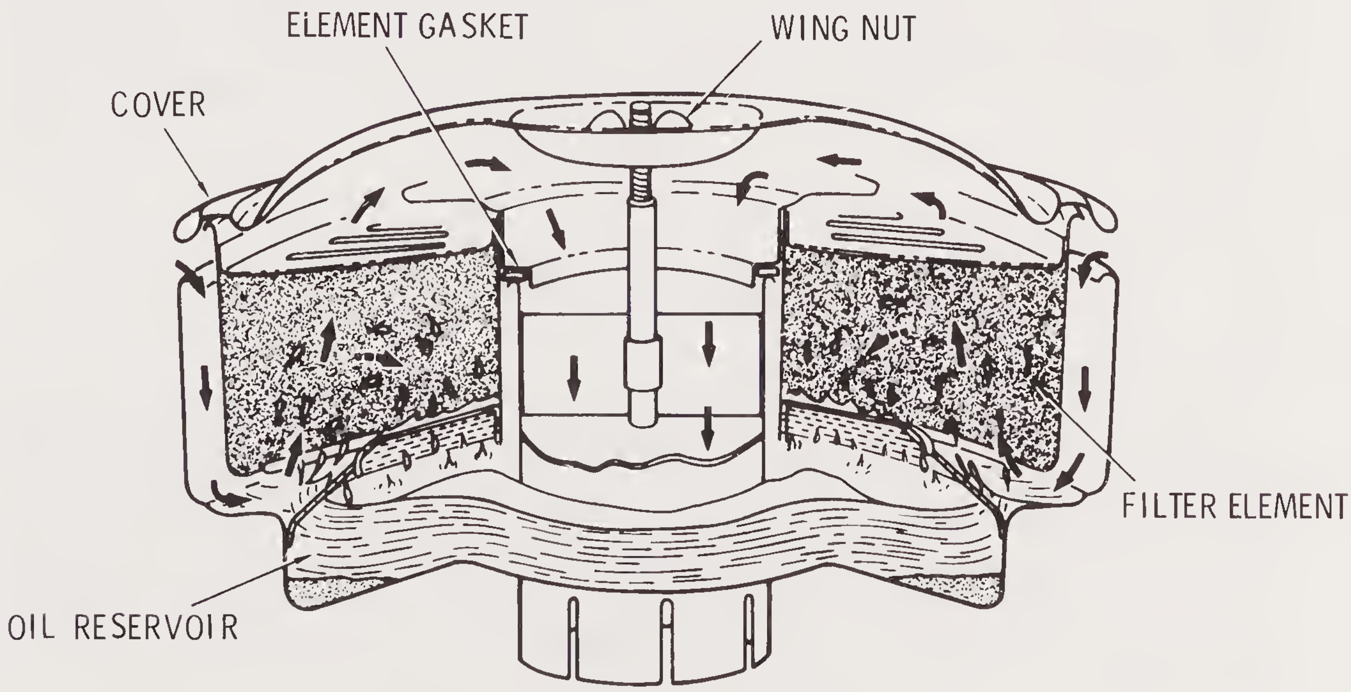



**Fig. 13-8. Wet-type air cleaner.**

the top of the main body. After the air passes through the gauze, it hits the cover plate and is deflected down through a passage to the carburetor. The oil is kept at a level that allows normal engine and vehicle vibration to constantly splash the surface of the gauze through which the air passes. The sticky oil attracts fine dirt and dust particles and then forms droplets that fall back into the reservoir, where the contaminants can settle out. The advantage of this system is that only occasional maintenance, consisting of cleaning the gauze and container with solvent and replenishing the oil supply, is necessary.

The dry type of air cleaner consists of a removable metal canister with an air horn and a disposable paper cartridge. Air enters through the air horn, which is designed to accelerate the airflow. As the air enters the canister it is allowed to slow so that heavier dirt particles can fall out. The remaining contaminants are removed by the paper cartridge. Recommended change intervals are determined by operating conditions.

## INTAKE MANIFOLD

The intake manifold, being a part of the fuel system, delivers and distributes the air-fuel mixture to the cylinders, prevents condensation, and assists in the further vaporization of the air-fuel mixture.

The intake manifold should be as short and as straight as possible to reduce the chances of condensation between the carburetor and cylinders. To assist in vaporization of fuel, some intake manifolds are designed so that part of their surface can be heated by hot exhaust gases. For this purpose a heat-control valve is placed in the exhaust manifold, which deflects the gases toward the hot spot in the intake manifold when the temperature around the engine is low. As the engine temperature rises, less exhaust is directed through the intake manifold.

All fuel in the intake manifold must pass over the hot spot before entering the cylinders. It does not contact the entire mixture at once, which helps keep the temperature down. Because of the hot spot, unvaporized particles that remain in the air-fuel mixture tend to vaporize instead of being carried into the cylinder as liquid particles.

## EXHAUST MANIFOLD

The exhaust manifold carries the exhaust gases of combustion from the engine cylinders. This must be accomplished with as little back pressure as possible. They may be single iron castings or made of formal steel in sections. They must have a smooth interior surface without abrupt change in size. The shape of the exhaust manifold has an appreciable effect on the scavenging action of the engine by using high-speed exhaust gases to create a vacuum that aids in the removal of exhaust from the cylinder.

## MUFFLER

The muffler is designed to smooth the pressure of the exhaust gases and to discharge them to the atmosphere with a minimum of noise. It is connected to the middle or near the end of the exhaust pipe.

The pressure of gases in the cylinders of an internal combustion engine is still high enough when the exhaust valve opens to cause them to escape with a loud sound. An efficient muffler not only deadens the sound of the exhaust but also offers a minimum resistance to the gas escape. Any resistance to the gas escape causes a back pressure against the piston of the engine during the exhaust stroke and thus reduces the engine power and speed.

To be effective, a muffler has several concentric chambers with openings between them. In operation, the gas enters the inner chamber, which acts as a reservoir, expands as it works its way through a series of holes into the other chambers and finally to the atmosphere.

## FUEL TANKS

Fuel tanks serving internal combustion engines are made in a number of sizes and forms, depending on the capacity of the engine. The fuel tank may be located at any convenient point, except in the gravity flow system, where the tank must be mounted above the engine.

Fuel tanks are usually made of thin-gauge metal or plastic. An

inlet for refilling and an outlet in the side or top of the tank leading to the fuel pump completes the fuel connections.

The outlet pipe, fitted for the fuel line connection, extends down into the tank close to the bottom. This prevents sediment accumulating at the bottom of the tank from being drawn into the fuel line.

Large tanks such as are employed for industrial and automotive use may be provided with baffle plates to provide additional strength and to prevent fuel from surging and splashing around the tank due to movement. As noted in Fig. 13-9, notches or perforations are provided in the baffle plates to permit fuel to flow freely through the compartments. A drain plug may be provided for draining and cleaning the tank when necessary. Old fuel-tank systems, used before the introduction of emission-control legislation, were simply vented to the open atmosphere. Modern automotive and industrial fuel systems are equipped with complex storage and retrieval venting systems designed to eliminate the emission of evaporated fuel vapor into the atmosphere. These systems employ some method for condensing fuel vapors and returning them to the tank, or they have a storage system which is purged into the intake manifold while the engine is running.

## FUEL GAUGES

Early types of fuel gauges were mechanically operated, and the indicator was incorporated as a single unit within the tank, with the

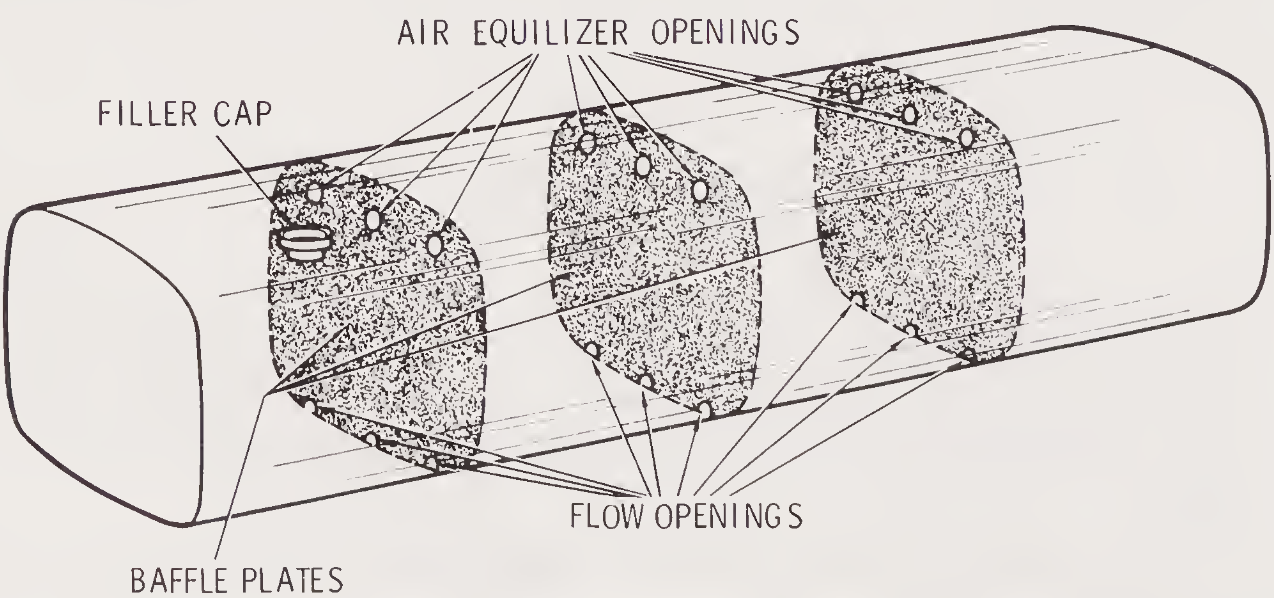



**Fig. 13-9. Typical baffled fuel storage tank showing filler opening.**

fuel-tank float and operating mechanism. The modern gauge type is electrically operated and has the operating mechanism and float within the tank, but the indicator is located on the instrument panel.

A typical electrically operated fuel gauge is shown in Fig. 13-10. In this arrangement the fuel indicator consists of two coils spaced 90° apart, with an armature and integral pointer at the intersection of the coil axis. The tank unit consists of a housing enclosing a rheostat or resistance unit with a brush which contacts the resistance unit. This contacting brush is actuated by the float arm movement, which in turn is controlled by the height of the fuel in the tank.

Variations in resistance (height of fuel) change the value of the indicating unit coils so that the pointer indicates fuel level. A calibrated friction brake is included in the tank unit to prevent wave motion of the fuel in the tank from oscillating the pointer on the indicating unit.

## FUEL INJECTION SYSTEMS

This type of system, because it affords a means of precisely controlling the air-fuel ratio for every designated engine operating condition (and, thereby, of controlling exhaust emissions to limit pollutants), is rapidly coming into wider use for industrial and

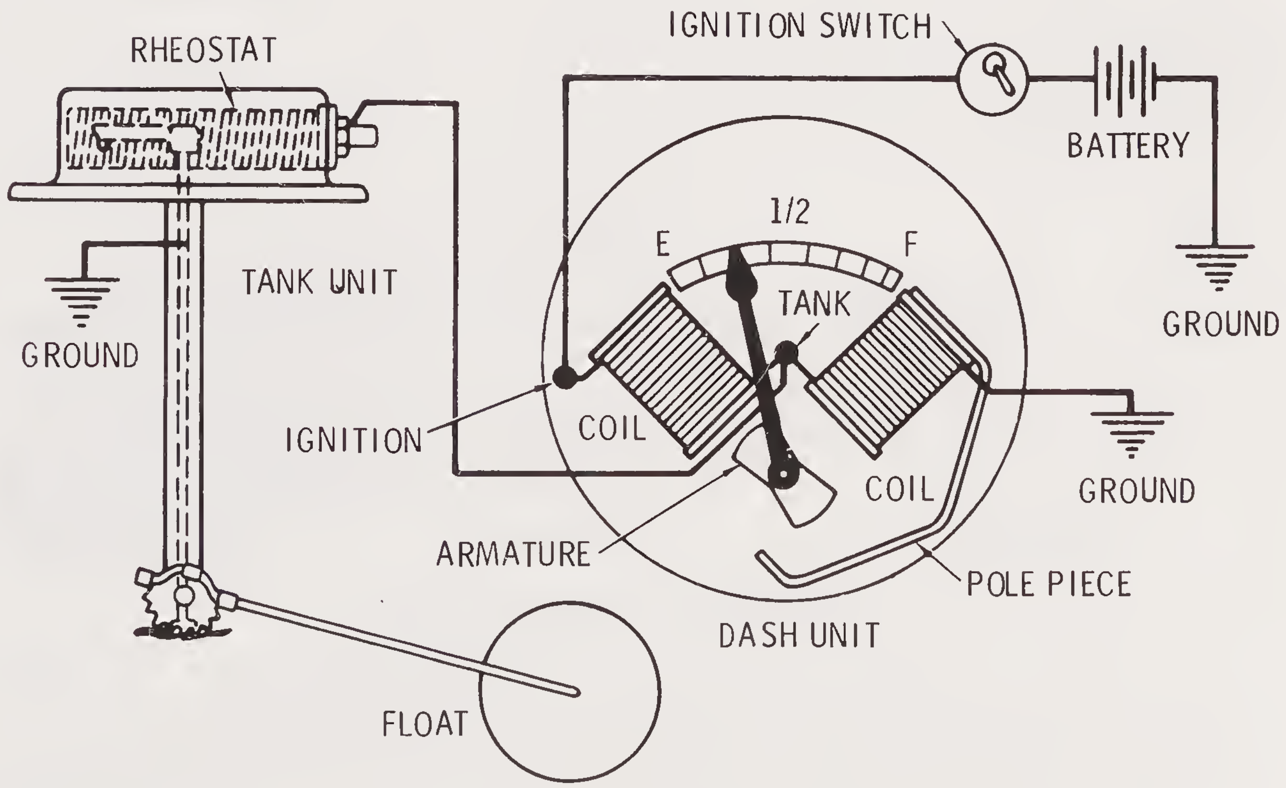



**Fig. 13-10. Wiring diagram of typical actuated fuel gauge.**

automotive applications, despite the fact that it is much costlier than a carburetor system and more critical to maintain. Originally developed for diesel engines, the first applications to gas engines were for sports and racing cars that benefited from the superior acceleration and top-speed characteristics afforded by the improved mixture-ratio qualities. Development of compact electronic controls made this system feasible for average over-the-road gas vehicles.

A typical American-design system is called *electronic fuel injection* (EFI). All the components mentioned at the beginning of this chapter are also used with this system (i.e., a storage tank, an intake manifold, an exhaust manifold, tubing, a muffler, a fuel gauge, a fuel filter and an air cleaner). In addition, this system also requires a fuel pump. Most of these components are the same as (or similar to) those used in a carburetor system, except that both fuel and air filtering must be as effective as possible (better filters and, in some cases, two or more fuel filters are used)—and the intake manifold may also be modified by the addition of controls. See Fig. 13-11.

Other components—in addition to the preceding—are also needed. The basic component is an *electronic control unit* (ECU),

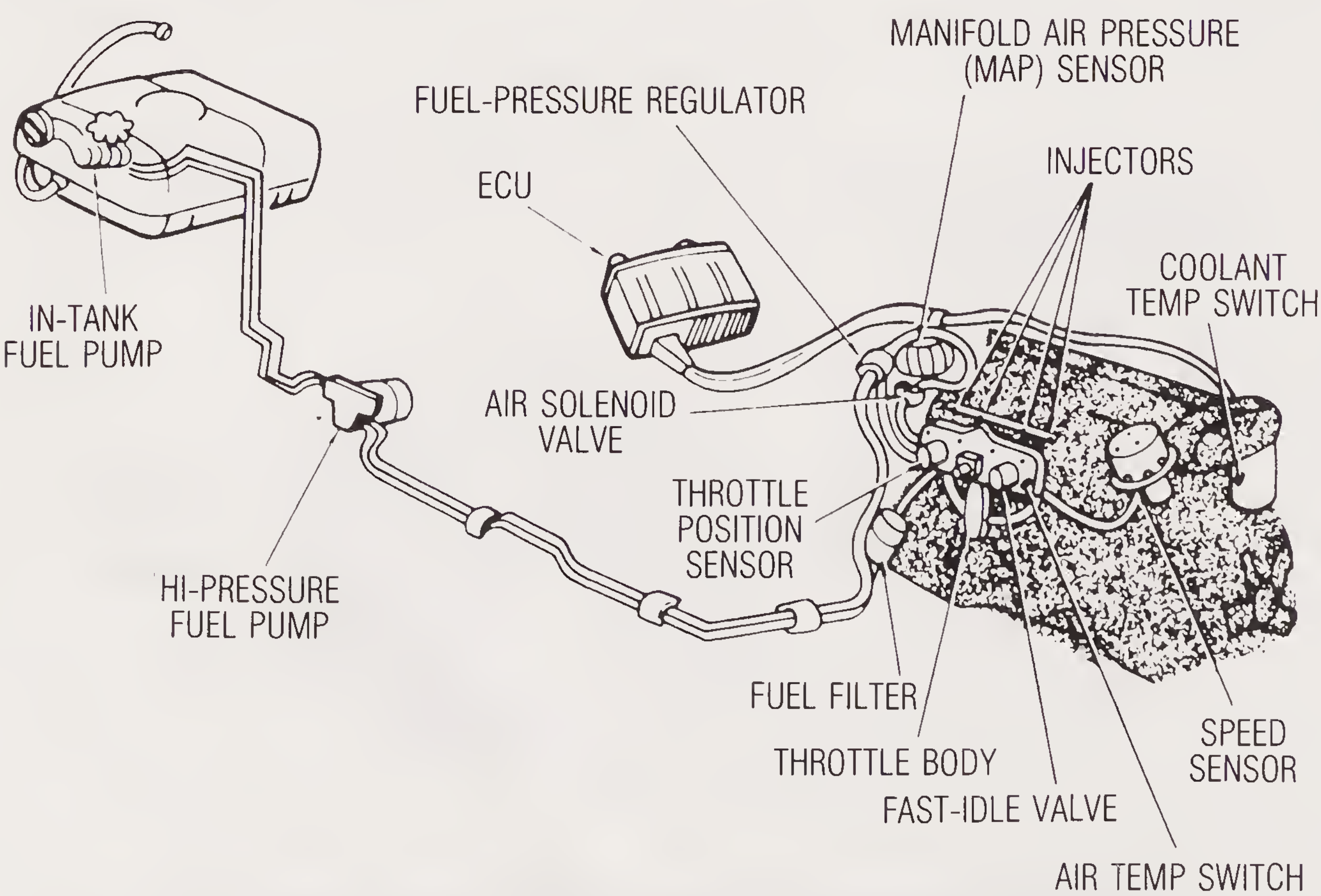



**Fig. 13-11. Typical electronic fuel injection (EFI) system.**

the "brain" of the system. Various operating conditions are monitored, the information is continuously fed to the control unit, and the control unit correspondingly determines the amount of fuel being fed into the air-fuel mix. As with a carburetor system, the throttle controls air intake, but unlike a carburetor system, the amount of fuel injected into the airstream is metered entirely by the control unit (*not* by the suction of a venturi). In addition to metering fuel for all operating conditions, the control unit also increases the airflow (and fuel) for cold starting (provides a "fast idle"). Fuel injection systems will be covered in more detail in Chapter 14.

## COMBUSTION

By definition, *combustion* is a more or less rapid chemical union of fuel with oxygen, whose combination is sufficiently energetic to evolve heat and light. In gas engines, combustion is the steady progressive burning of the intake charge at a uniform rate.

*Detonation* is very rapid oxidation, that is, an explosion that causes a very sudden rise in pressure. In gas engine operation this occurs after the flame has traveled partway across the combustion chamber. This results in loss of power and overheating because the rise in pressure is almost instantaneous and the resulting energy cannot be transmitted to the piston as efficiently as when the pressure rise is more gradual. When detonation takes place, it produces a hammerlike blow against the piston head and the engine is said to "knock."

Detonation may harm an engine in several ways. In extreme cases, pistons have been shattered and rings and cylinders damaged. Other effects of detonation may be overheating, broken spark plugs, overloaded bearings, high fuel consumption, loss of power and frequent need for overhaul.

## OCTANE RATING

In the development of antiknock fuels by improved refining processes it became necessary to establish some standards of rating, resulting in the octane method. In this method two hydrocarbons, octane and heptane, were used.

The ability of a fuel to resist detonation is measured by its octane rating. The octane rating of a fuel is determined by matching it against mixtures of normal heptane and octane in a test engine and under specified test conditions until a mixture of the pure hydrocarbons is found which gives the same degree of engine knocks in the engine as the gasoline being tested. The tendency of a fuel to detonate, however, varies in different engines, and in the same engine under different operating conditions.

Since engines are designed to operate within a certain octane range, it follows that their performance is improved with the use of the higher-octane fuel within that range if timing of the combustion is changed accordingly. In this connection it should be noted, however, that if an engine operates satisfactorily at the upper limit of its fuel octane range, its performance will not be improved if fuel that exceeds the designed octane range is used.

*Tetraethyl lead* is the most popular of the compounds added to gasoline to suppress knocking. Improved refining methods also have produced fuels of greater antiknock quality. Tetraethyl lead and other antiknock compounds are effective because they reduce the rate of burning of the fuel, thus tending to prevent explosive burning or detonation.

| Ratio | For 1 gal. of gasoline add ounces of oil shown | For 2 1/2 gal. of gasoline add ounces of oil as shown | For 5 gal. of gasoline add ounces of oil as shown | For 10 gal. of gasoline add ounces of oil as shown |
|---|---|---|---|---|
| 16:1 | 8 oz. | 20 oz. | 40 oz. | 80 oz. |
| 24:1 | 5 oz. | 13 oz. | 27 oz. | 53 oz. |
| 32:1 | 4 oz. | 10 oz. | 20 oz. | 40 oz. |
| 48:1 | 2 1/2 oz. | 7 oz. | 13 oz. | 27 oz. |
| (50:1) | | | | |

**Fig. 13-12. Table showing common fuel mixtures for 1, 2½, 5, and 10 gallons of gasoline.**

## GAS-OIL MIXTURE FOR TWO-STROKE-CYCLE ENGINES

Two-stroke-cycle engines require an oil-gasoline mixture in a certain volumetric ratio for their proper operation. The best oil to use is that recommended by the engine manufacturer.

Most engines operate satisfactorily on regular automotive gasoline, which is available almost everywhere. Gasoline containing a large amount of tetraethyl lead *should not be used*, since it tends to foul up the exhaust ports, making frequent cleaning necessary.

Manufacturer's instructions as to the grade and amount of oil to be mixed with each gallon of gasoline should be carefully adhered to. In cases where such information is not readily available, a fuel mixture chart such as shown in Fig. 13-12, will be helpful.

With reference to our table, it will be noted that the volumetric ratio between the desirable amount of oil to be added to each gallon of gasoline differs a great deal, depending on the size of the engine and other factors dealing with its construction.

CHAPTER 14

# Carburetors and Fuel Injection Components

The proportions of air to gasoline (each by weight) for gas engine operation under different running conditions may be said to have an approximate range from 12 to 17. Hence, the average (about 15 parts of air to 1 part of gasoline) may be called a *medium mixture* and, on this basis, a *rich* mixture may be defined as one having a proportion of air less than 15 to 1 while a *lean* mixture is one having a proportion of air greater than 15 to 1.

## AIR-FUEL RATIO

A richer mixture is needed for starting an engine (and the mixture must be enriched in relation to the coldness of the engine)—and is also needed to some extent (which depends on engine temperature,

atmospheric pressure and other factors) when a running engine is stressed by acceleration or an overload (such as when the vehicle is climbing a steep hill). On the other hand, a too rich mixture not only wastes fuel, it also becomes a pollutant (because an insufficient amount of air cannot supply the oxygen needed for complete combustion). On the whole, it is desirable to operate an engine on as lean a mixture as possible for the immediate circumstances under which it is operating.

Unfortunately, there is no simple formula for the "proper mixture" for all vehicle or industrial gas engines under all operating conditions, nor is there a simple solution to the problem, especially if fuel economy and pollution effects must be taken into account, together with engine performance. For maximum safety of locomotion, an over-the-road vehicle must be capable of sufficient acceleration and deceleration to avoid dangerous situations. To avoid the increasingly stringent pollution-control requirements it must either burn all its fuel, at all times, in a superlatively efficient manner, or must waste power (and fuel) converting the inefficiently burned emissions. These objectives are, in many respects, also opposed, so that no single, simple method of accomplishment is apparent.

A carburetor depends primarily on the suction of a venturi to meter fuel into an airstream and to thus maintain an approximate 15-to-1 air-fuel ratio throughout most engine operating conditions. The exact ratios for idling and normal operating conditions are adjustable, excess starting fuel is furnished by choking (disproportionately reducing the air supply), and the stresses of acceleration and overload are accommodated by pumping relatively more fuel whenever the accelerator is used to open the throttle. Air-fuel mixing (to assure optimum oxidation of all "particles" of the fuel) is accomplished by turbulence in the intake manifold.

An injector depends solely on the preprogrammed commands of its system control unit (or injection pump) to meter the fuel in ratios required for all operating conditions monitored by the system, excepting only that there may be certain manual adjustments which can be made to the "commands." Air-fuel mixing is accomplished by high-pressure atomization of the fuel into the airstream, and by turbulence.

## CARBURETOR OPERATING PRINCIPLES AND TYPES

By definition, a carburetor is a device for breaking up gasoline into a very finely divided state and mixing it with air in automatically varying proportions to meet the variable running conditions of a gas engine. Although there is a considerable difference in the appearance of carburetors used on various types of engines, they all operate on the same basic principle.

Probably no part of a gas engine has undergone a more useful improvement during the years than has the carburetor. The improvements that have taken place made it possible to obtain a great range of engine speeds, a reduction in fuel consumption, more nearly perfect combustion and increased ease of starting.

The primary functions of a carburetor are: (1) to break up the gasoline into as small particles as possible, and (2) to mix these particles with air in the proper proportions.

In this connection it should be noted that there must not be too much gasoline spray, as fuel would be wasted either by being decomposed into soot or unburned because of insufficient oxygen in the air to burn it. Again, too much air with ignition of the mixture would result in unsatisfactory operation.

To present the principles involved progressively, two cases will be considered in which the air supply is:

1. Constant.
2. Variable.

The four essential elements of the first type are:

1. Fuel chamber.
2. Discharge nozzle.
3. Mixing chamber.
4. Throttle.

These essential elements, with the exception of the throttle, are shown in Fig. 14-1.

The sectional view illustrates a fuel chamber and a mixing chamber or draft tube, the two being connected by a small pipe or

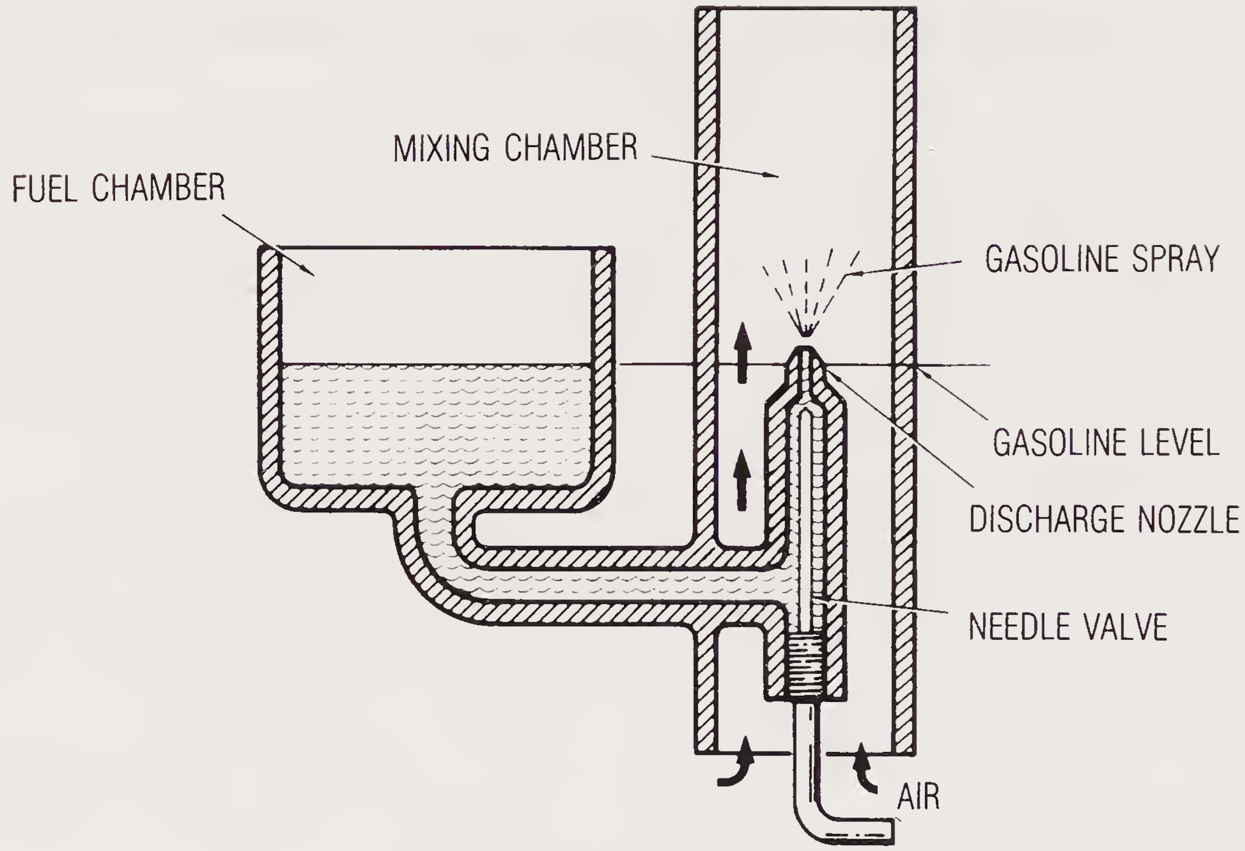



**Fig. 14-1. Elementary carburetor principles.**

duct which terminates at the discharge nozzle, arranged so that the supply of gasoline to the nozzle may be regulated by the needle valve. The lower end of the draft tube is open to the atmosphere and the upper end connects with the inlet manifold of the engine.

In explaining the carburetor operation, it is assumed that the fuel chamber is filled with gasoline and the supply maintained at a level very near the elevation of the top of the spray nozzle. Assuming the engine to be running with unvarying load and speed, the average vacuum produced in the manifold will remain constant and the excess atmosphere pressure outside the mixing tube will force air up through the mixing tube.

When the needle valve is opened, atmospheric pressure will also force gasoline through the fine bore of the discharge nozzle, and will enter the mixing tube in a finely divided state, that is, in the form of a spray. By adjusting the needle valve so that the gasoline and air admitted will be in proper proportions to suit the operating conditions of the engine, a correct mixture will be obtained and the engine will operate satisfactorily and economically.

In most engines, however, the speed and load are constantly subject to change. These conditions must be met with a mixture of different proportions, that is, the proportions of gasoline to air must

be changed. To meet this requirement, the carburetor must be constructed so that the air supply can be automatically varied. In such an arrangement there are two air supplies, known as:

1. The primary air.
2. The secondary air.

Fig. 14-2 shows an elementary carburetor having the means of automatically varying the amount of air that mixes with the gasoline. Comparing this with Fig. 14-1, it will be noted that both carburetors are identical with the exception of the air valve shown at the right. This air valve is a form of check valve of light construction and is normally held closed by a spring.

*In operation*, when the reduction of pressure in the mixing chamber becomes great enough, the excess atmospheric pressure on the outside overcomes the force of the spring and the valve opens, admitting additional air supply, which is called the *secondary air supply*.

The degree of opening of the valve and, consequently, the amount of secondary air admitted will evidently depend on the

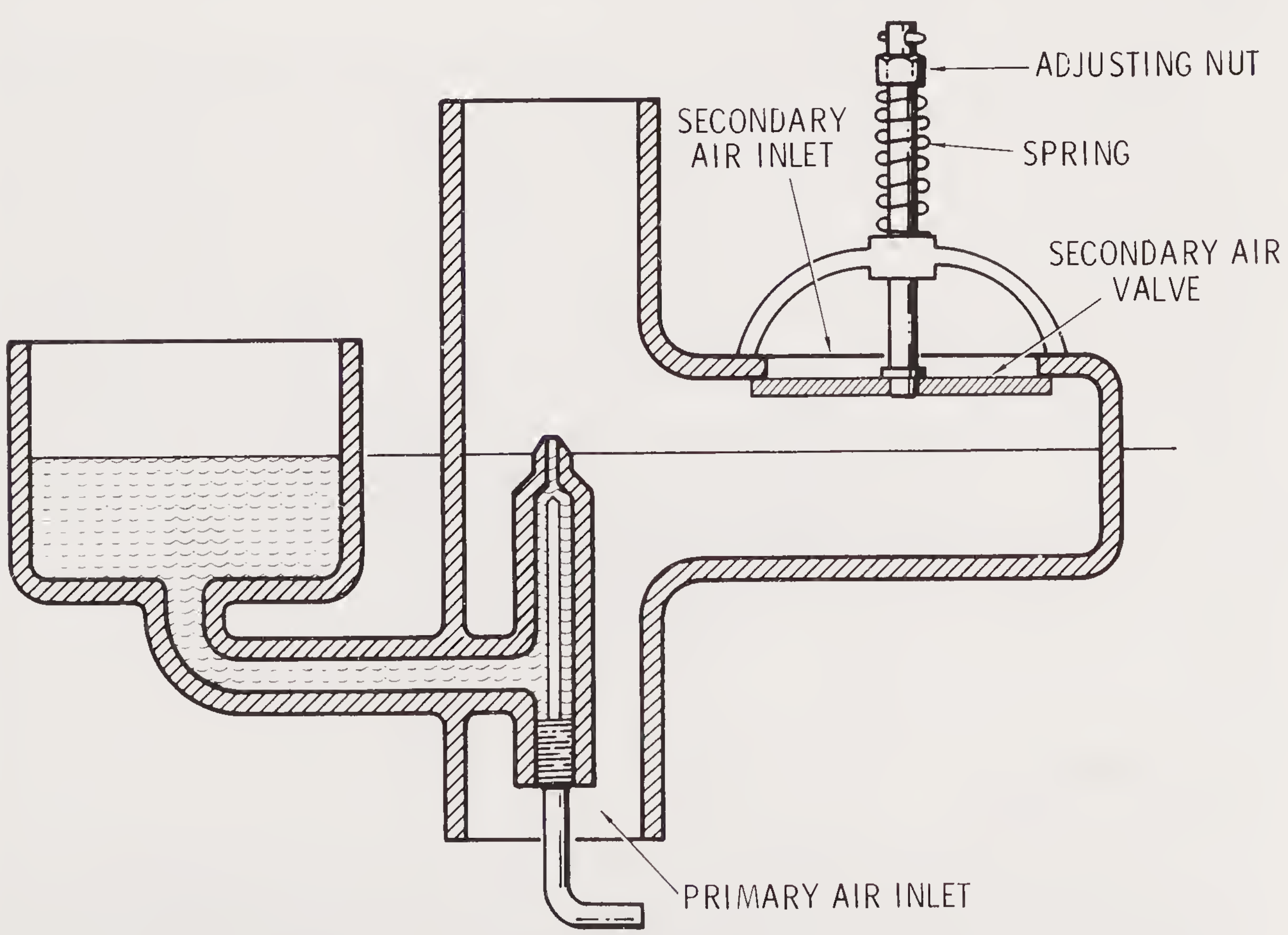



**Fig. 14-2. Elementary carburetor with primary and secondary air supply.**

difference of pressure inside and outside the mixing chamber. This secondary air supply can be adjusted by means of the nut on the valve stem.

*In operation*, if the engine is running at slow speed, there will not be enough drop in pressure in the mixing chamber to open the air valve and sufficient air for a proper mixture will come in through the primary air inlet.

Now, if part of the load on the engine is removed so that it will run, say, twice as fast and if the air valve is held closed, the mixture will become too rich. Although the higher speed of the engine will cause a further reduction of pressure in the air chamber, which will cause more gasoline and air to be delivered to the cylinder, the excess air will not have the same proportion to the excess gasoline as in the original mixture. That is, if the original mixture were, say, 15 to 1, the ratio would drop to, say, 12 to 1 and would be too rich for satisfactory operation.

The excess of gasoline is due to the fact that, in order to get, say, twice the amount of air through the primary inlet, the degree of vacuum in the mixing chamber has to be more than doubled to compensate for the increased frictional resistance set up by the higher velocity of the incoming air.

Since the gasoline flowing through the nozzle is not subjected to such excess frictional resistance, more than double the amount of gasoline will flow into the mixing chamber, causing the mixture to become too rich. If the air valve is now released so that it is held only by the spring, the higher vacuum in the mixing chamber due to the increased speed of the engine will cause the valve to open and admit additional or secondary air to make up for the inadequate supply. If the spring has been properly adjusted, the mixture will be in proper proportion for the higher engine speed, that is, neither too rich nor too lean. Fig. 14-3 shows the carburetor action at the higher speed with the air valve partly open, admitting secondary air.

## Choke Valve

In practically all carburetors, a valve is placed in the primary air passage (as shown in Fig. 14-4) so that the amount of air and vacuum can be regulated. This is called the choke valve. This valve may be

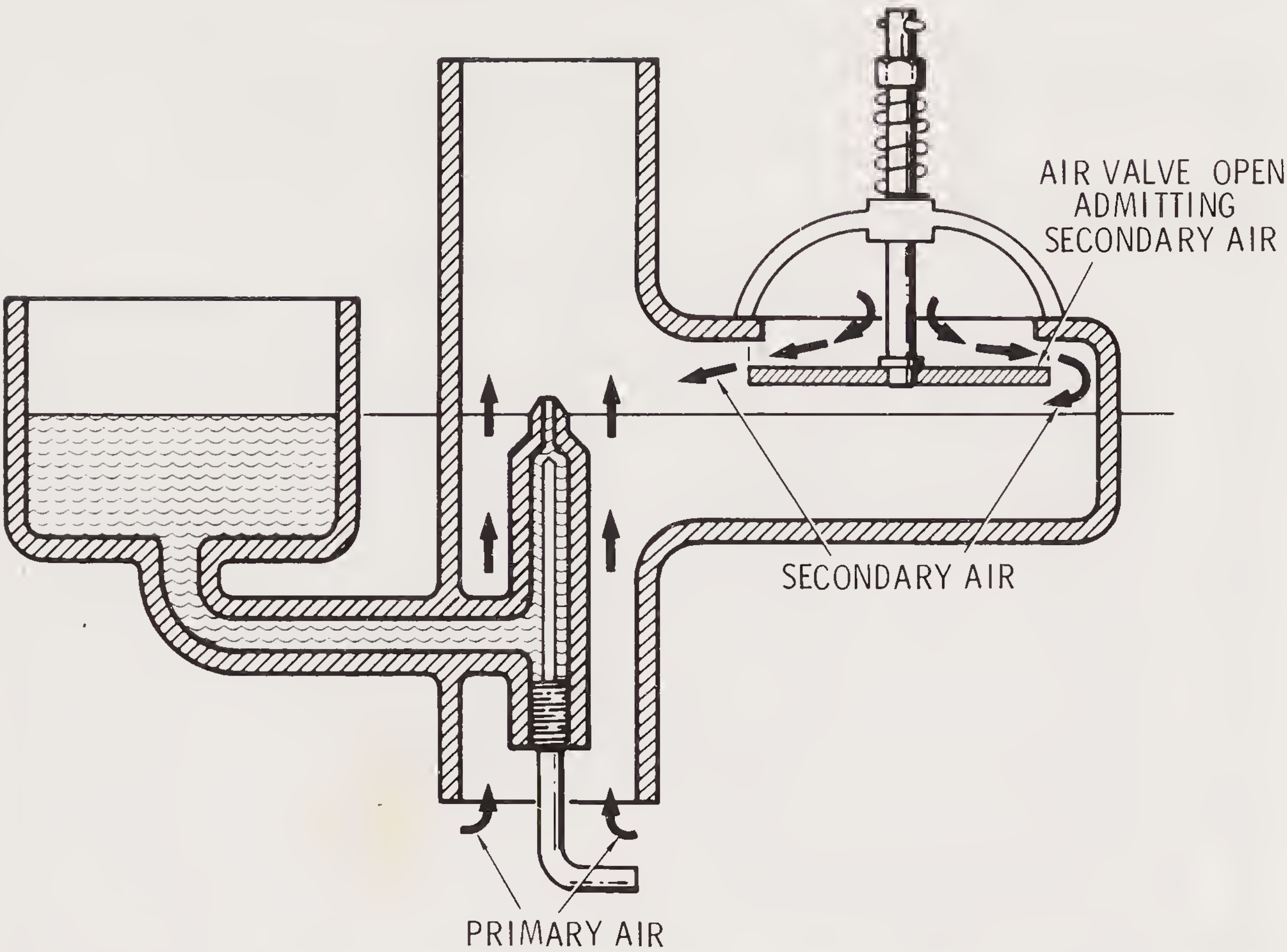



**Fig. 14-3. Variable secondary air supply controlled by an automatic air valve.**

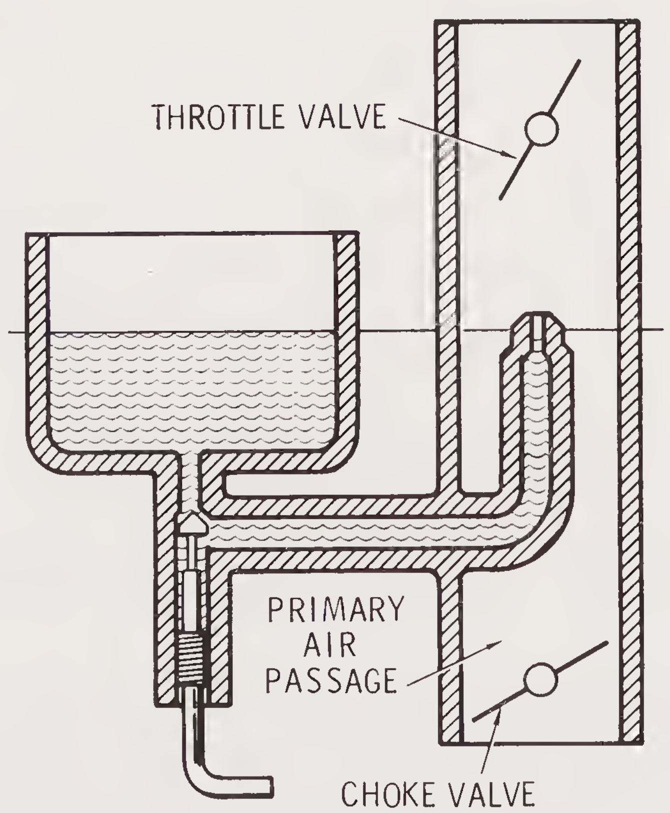



**Fig. 14-4. Choke valve for regulating the primary air and manifold vacuum in starting.**

manually controlled, but is normally actuated by an automatically operated valve.

## Carburetor Floats

The function of the carburetor float is to maintain automatically a supply of gasoline in the receiving chamber at very near the same level as the top of the spray nozzle. Since a float is generally used to accomplish this, the chamber is popularly called the *float chamber*. In the float-feed method of maintaining a constant level of gasoline in the receiving chamber, a cork or hollow metal or plastic float is placed in the float chamber. It is connected so as to operate the gasoline inlet valve, usually by means of levers. These are arranged in such a manner that as gasoline enters the float chamber through the inlet valve, the float rises and closes the valve, thus shutting off the supply when the gasoline reaches the desired level.

In some instances the overflow method is used whereby gasoline is maintained at the necessary level by a surplus volume being pumped or otherwise forced into a chamber whence the overflow returns to the main supply, the height and capacity for the return of the overflow maintaining the necessary level with reference to the discharge nozzle. Figs. 14-5 and 14-6 show two elementary float-feed systems of the offset type and illustrate downflow and upflow, respectively.

In Fig. 14-5, the float is attached to a central stem having at its upper end a needle valve connected by a threaded joint which provides the means of adjusting the gasoline level. The lower end of the stem works in a guide that keeps it in a central position.

*In operation*, as gasoline in the float chamber is supplied to the carburetor, the float moves downward with the receding level of the liquid and the needle valve opens and admits additional supply, which causes the float to rise and finally close the inlet when the liquid reaches the predetermined level controlled by the level adjustment.

The operation in Fig. 14-6 is similar except that it is arranged to admit the gasoline at the bottom of the float chamber. Fig. 14-7 illustrates the location of the float, whose movement is transmitted to the inlet needle valve by a lever. The arrangement shown in Fig. 14-7 employs a lever pivoted as shown, resting on top of the float.

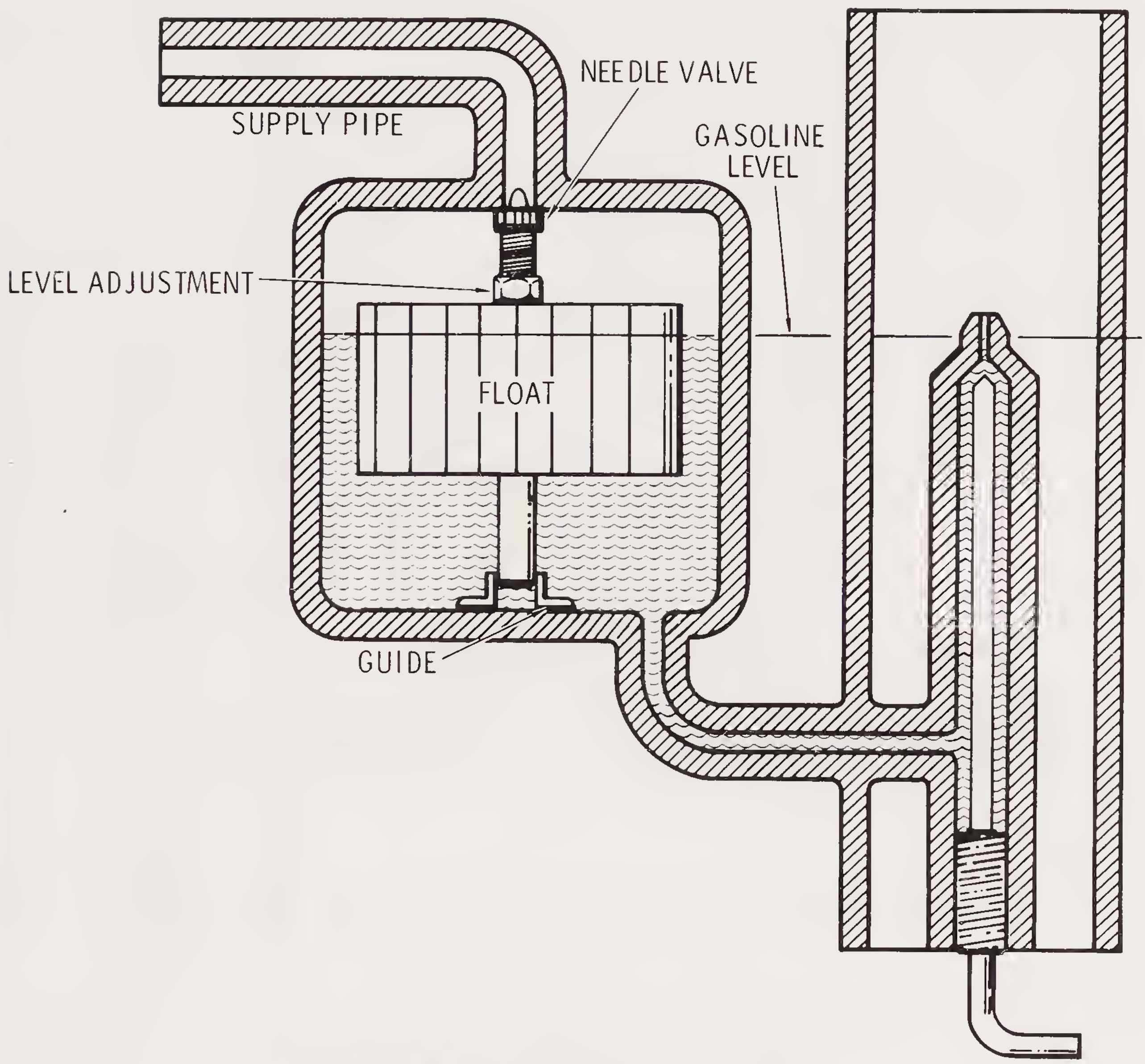



**Fig. 14-5. Direct connected float feed.**

*In operation*, on a receding level, the float is pulled downward by gravity, thus opening the valve. As the level rises, the buoyance of the float pushes up, closing the valve.

## THE VENTURI EFFECT

In a mixing chamber of variable cross section the quantity of air or mixture which passes any section in a given time is the same, but its velocity is inversely proportional to the areas of the sections. The pressure is greatest at the largest section and least at the smallest. This is known as the Venturi effect or principle. The Venturi principle has been applied to the carburetor design by shaping the mixing chamber like the familiar hourglass.

By locating the discharge nozzle at the point of least cross

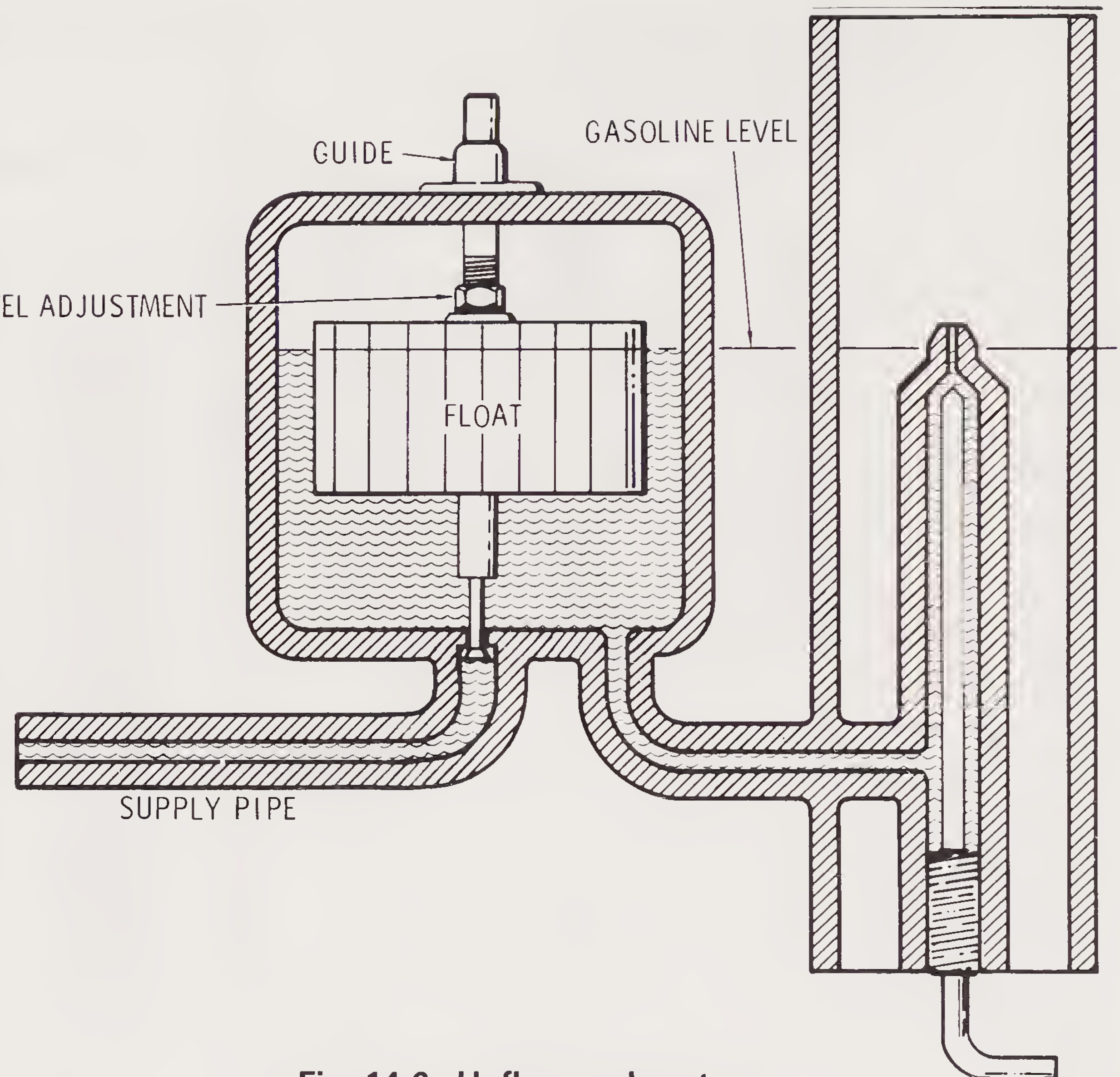



**Fig. 14-6. Upflow carburetor.**

section, the conditions are favorable for securing that marked economy of fuel which results from the use of high air velocities under low pressures. The greater the pressure drop at the nozzle, accompanied by a proportional increase in the air velocity, the finer the gasoline will be broken up or divided and the greater the percentage of the liquid that will be vaporized.

The very rapid agitation and internal motion of the mixture column, due to the restricted section of the venturi tube, tends to produce a homogeneous fuel charge. A lowering of the pressure lowers the temperature of the liquid through vaporization, hence, in venturi carburetors where any marked Venturi effect is sought, heating is advisable.

The advantages of the venturi tube as applied to carburetors may be summed up as follows: homogeneity of mixture; ease with which the mixing chamber may be heated either by air or water;

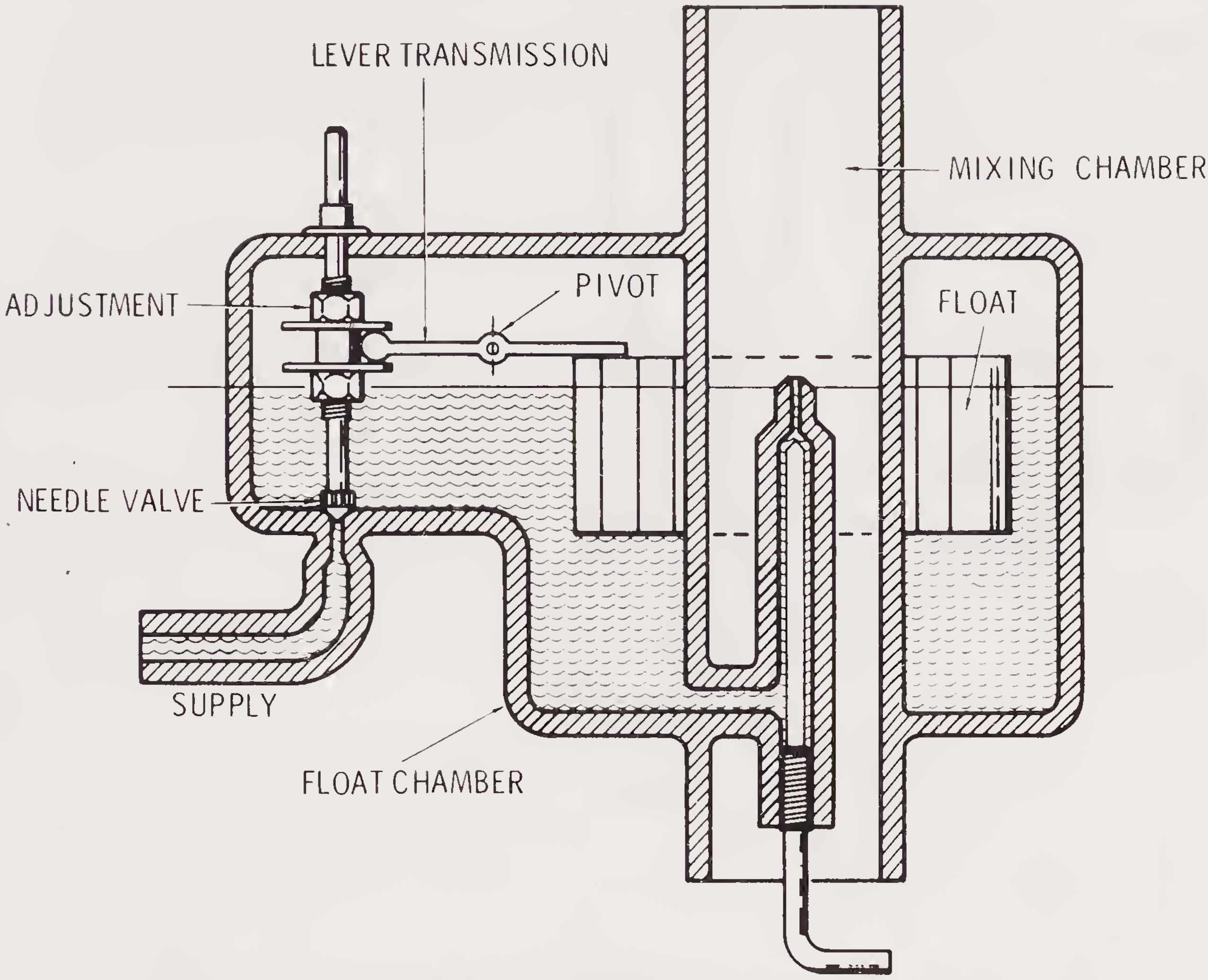



**Fig. 14-7. Float with lever connected to needle valve.**

the mixing chamber may be placed in any plane, thus adapting it to varied engine designs.

The Venturi principle is illustrated in Fig. 14-8. Here the mixing chamber is considerably reduced at **A**, which in operation gives low velocity of air-flow through the full-sized portions of the mixing chamber and very little pressure reduction; at the restricted section **A**, the velocity is greatly increased (depending on the reduction in cross-sectional area), which is accompanied by a considerable pressure reduction. This excess vacuum causes an increase in the percentage of the gasoline vaporized.

## Spray Nozzles

The amount of liquid passing through the nozzle may be varied by an adjustable needle valve. Some carburetors are fitted with two or more simple nozzles, the idea being that the several nozzles forming the unit, by coming into action progressively as the power

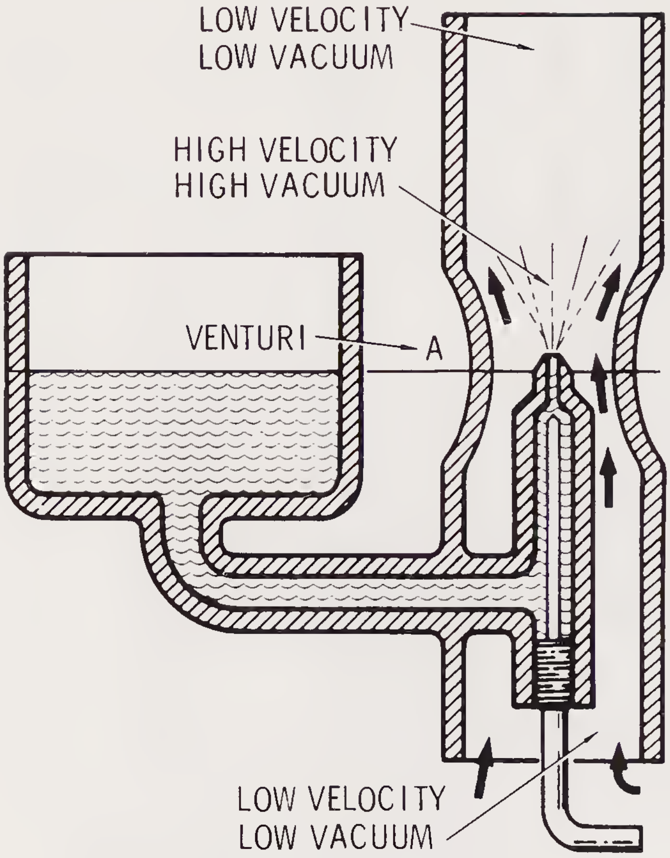



**Fig. 14-8. Venturi principle.**

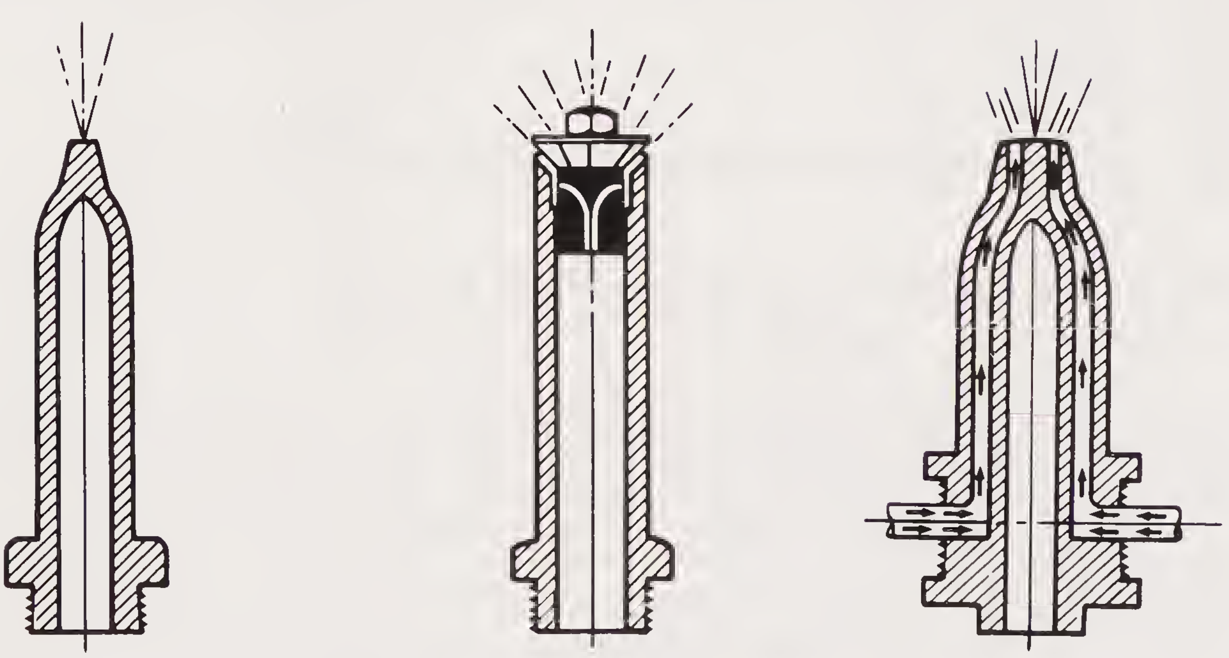


**Fig. 14-9. Various carburetor nozzles.**

demand increases, will provide the same effect as though several carburetors were used, each in turn being brought into action. See Fig. 14-9.

Whatever form is given to the nozzle, the effectiveness with which it can break up the fuel varies with the difference between the pressures at its two ends, and this pressure difference varies throughout the speed range of the engines.

Since the nozzle has a very small opening, even for the largest engines, it is easily stopped up, and the construction should be such that it may be cleaned easily.

## Air-Bleed Principle

Air bleed is the mixture of a small amount of air with the fuel before it leaves the nozzle. The purpose of the air bleed is to avoid too lean a mixture on low vacuum and too rich a mixture on high vacuum. Accordingly, the degree of vacuum in the mixing chamber may become so low, as when operating the engine at slow speed and light loads, that the mixture will become so lean as to cause the engine to miss or stop. To remedy this possibility, the air bleed is provided.

The application of the air-bleed principle to a typical *Stromberg* carburetor is shown in Fig. 14-10. *In operation*, at closed throttle or slow engine speeds, the fuel is delivered through the idle system as indicated. The fuel is taken from the base of the main discharge

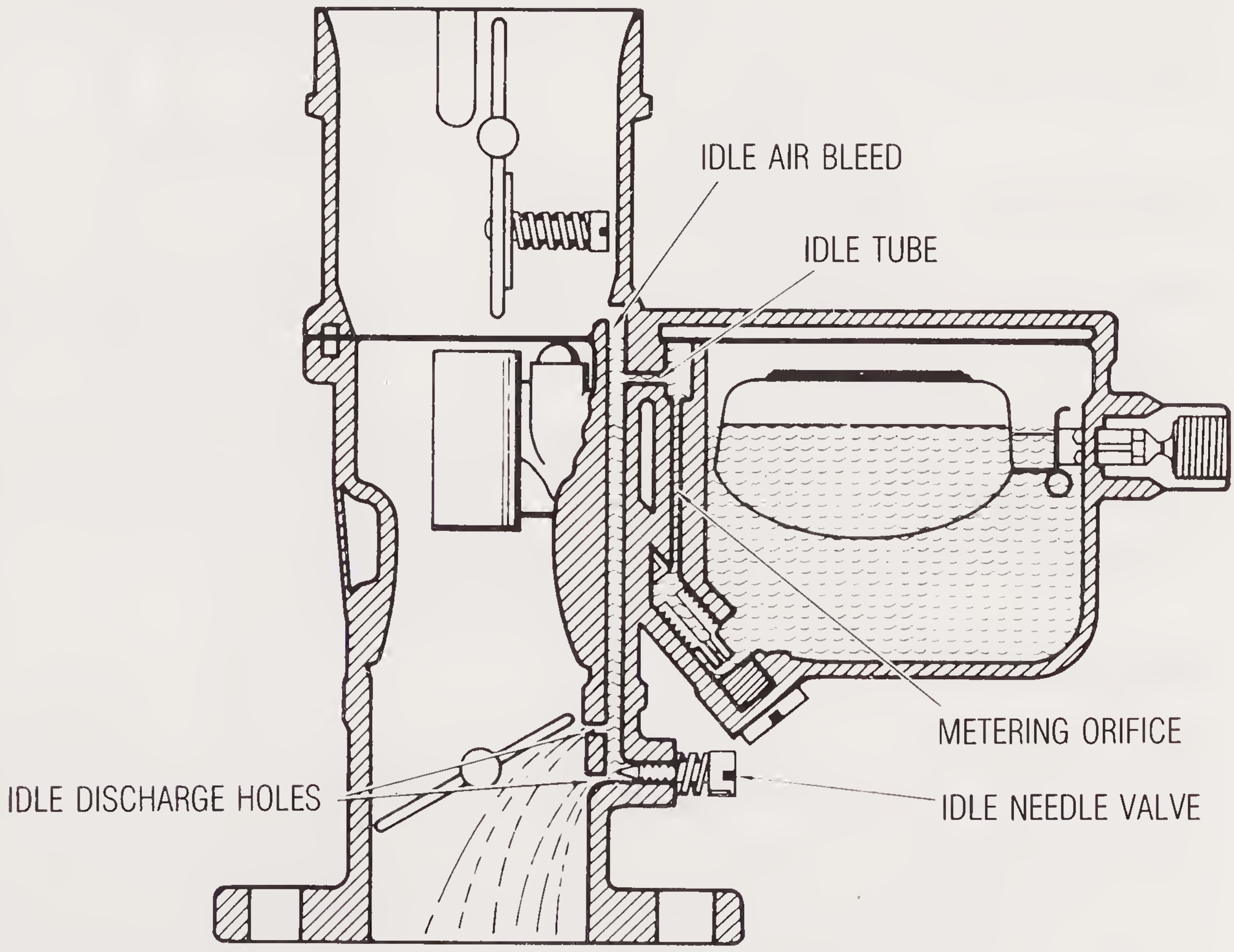



**Fig. 14-10. Air-bleed principle.**

jet, flowing into the bottom of the idle tube, where it is metered. From the tube it flows through the connecting channel where air from the idle air bleed is mixed with it so that a mixture of air and fuel passes down the channel and is discharged from the idle discharge holes. The idle needle valve controls the quantity of fuel discharged from the primary hole, thereby effecting the mixture ratio.

## Heating Methods

The object of heating is to promote vaporization. The methods of applying heat that is obtained from the exhaust gases or circulating water are, by the use of jackets, placed around the air supply pipe, the inlet manifold or around the float chamber bowl.

The latter method of heating is theoretically the best because heating the air supply or mixture results in raising the temperature of the incoming charge, with the result that it is in an expanded state so that less charge is taken in than would be at a lower temperature. The prevailing method, however, is to heat the mixture by jacketing part of the manifold and by passing some of the exhaust gases through the jacket.

## Economizer

This name is usually given to an air bleed fitted with a needle valve so that the amount of air entering the nozzle can be varied to suit the engine running conditions.

The amount of economizer action is controlled primarily by engine vacuum. As engine vacuum goes higher, the economizer allows additional air to enter the bleeder passages.

## Metering Rod

This device consists of a long metallic pin of tapered diameter fitted to the main nozzle in such a way that it measures or "meters" the amount of gasoline permitted to flow by it at various engine speeds. It may be operated by suitable connection with the throttle so that it moves in fixed relation to the opening or closing of the throttle, or by a piston operated by engine vacuum. It may be used as either

a primary or secondary adjustment of the gasoline supply to the nozzle.

In the construction shown in Fig. 14-11 the metering rod is controlled by the position of the throttle and is positive in its action. *In operation*, with the throttle wide open, the power mixture is delivered; with the throttle in intermediate positions, the gasoline supply is cut down to give the economy mixture. The economy range covers all engine speeds, except wide-open throttle.

## Accelerator Pump

To secure rapid engine acceleration, most carburetors are fitted with a specially designed pneumatic-type accelerator pump. A typical pump of this kind consists of a cylinder with a plunger containing

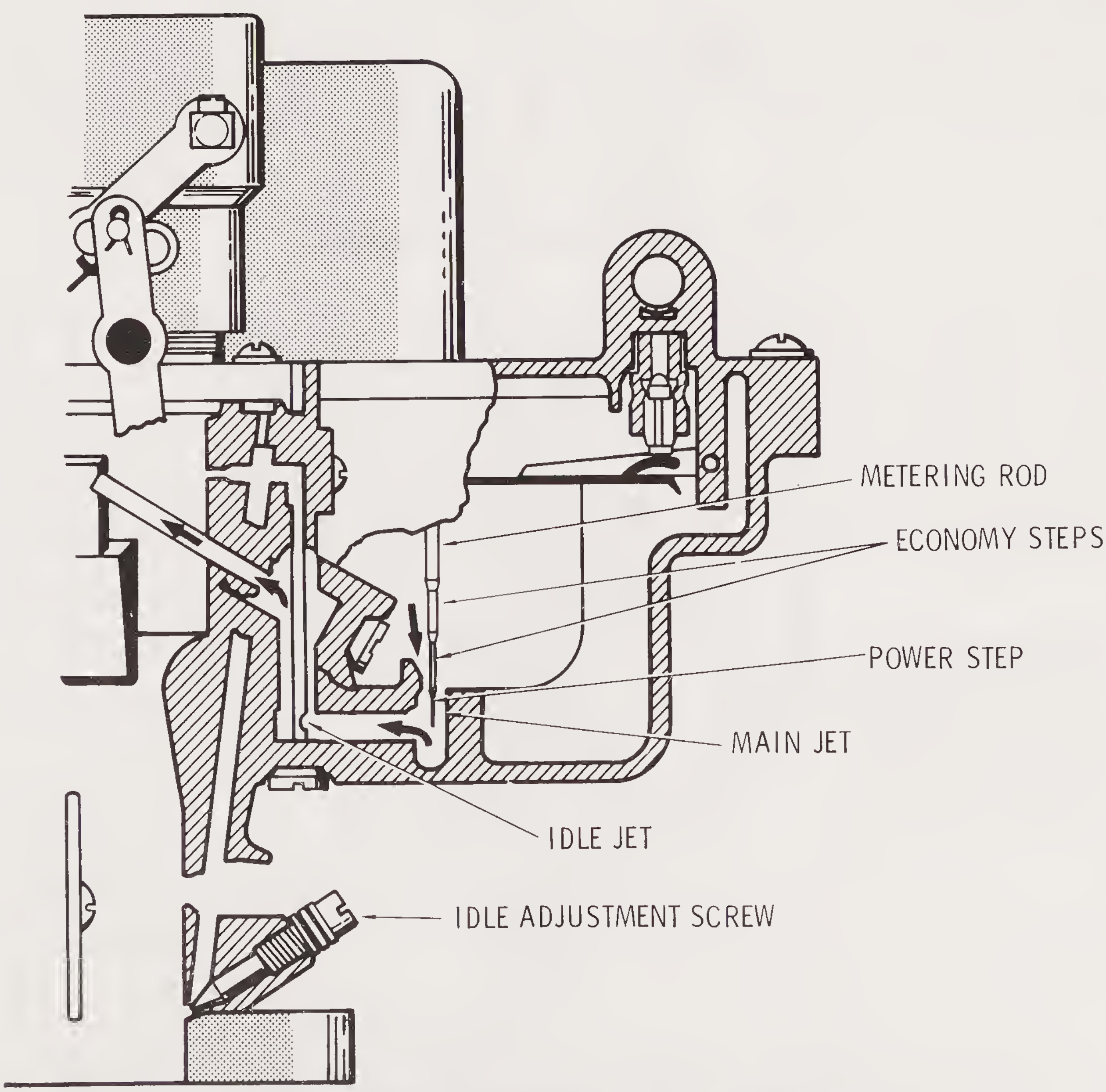



**Fig. 14-11. Carburetor illustrating the metering rod.**

a check ball and inlet and outlet valves. It is opened automatically by suitable connection with the throttle. See Fig. 14-12.

*In operation*, the upward movement of the plunger when the throttle is closed draws a predetermined amount of fuel into the bottom of the cylinder. The slightest opening of the throttle causes compression and forces discharge of gasoline through the accelerating nozzle, which points downward into the main venturi. When the throttle is fully opened, the discharge is usually continued for a few seconds by a spring linkage behind the plunger.

## Updraft and Downdraft Carburetors

Carburetors may also be classified as *updraft*, *downdraft*, and *side draft*, according to their position with respect to the intake manifold.

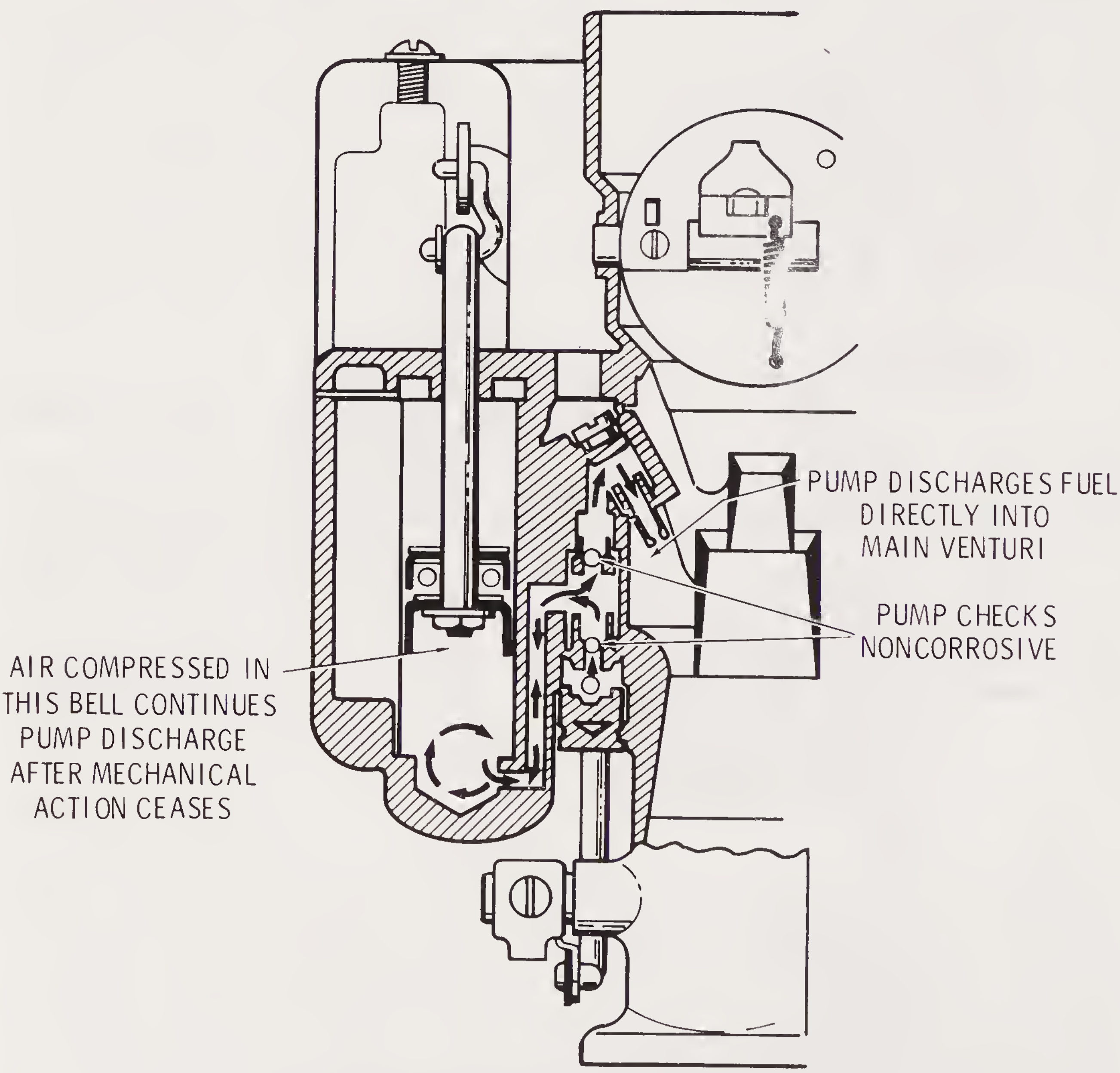



**Fig. 14-12. Accelerator pump.**

Thus, if a carburetor is mounted *below* the manifold, it is classed as an *updraft*, and if mounted *above*, it is a *downdraft* type. A side draft must be mounted even with the manifold and takes in air horizontally.

In early fuel systems it was necessary that the fuel flow down by gravity to the float chamber, making the updraft carburetor essential because of its low position. The introduction of mechanical fuel pumps, however, has largely eliminated this problem, so that late-model carburetors are usually of the downdraft type. In this design, the carburetor is placed above the engine. Air entering at the top passes downward, mixes with the fuel and then passes on to the manifold and engine.

Another type is known as the *horizontal* or *side draft* carburetor. Here the air-fuel mixture passes out to the engine manifold horizontally as noted in Fig. 14-13. It is used on lawn mower engines, on small auto engines, and on various high-performance engines. An advantage of this type is that it simplifies manifold construction, since it eliminates one right-angle turn.

## FUEL FLOW CIRCUITS

In the foregoing, the various elementary principles of carburetors have been fully dealt with. In order to meet the varying air-fuel ratios required by high-speed multicylinder engine carburetors, however, numerous paths must be provided through which the mixture must flow. These various paths, whose duty it is to properly prepare the mixture according to engine requirements, are generally termed *carburetor circuits* or *fuel flow circuits*.

There are five circuits through which gasoline may flow through the ordinary multicylinder engine carburetor. They are:

1. Float circuit.
2. Low-speed or idle circuit.
3. Main metering and high-speed circuit.
4. Pump circuit.
5. Choke circuit.

Other circuits in a carburetor will be either a variation or a combination of these. Because the high-speed circuit is unable to

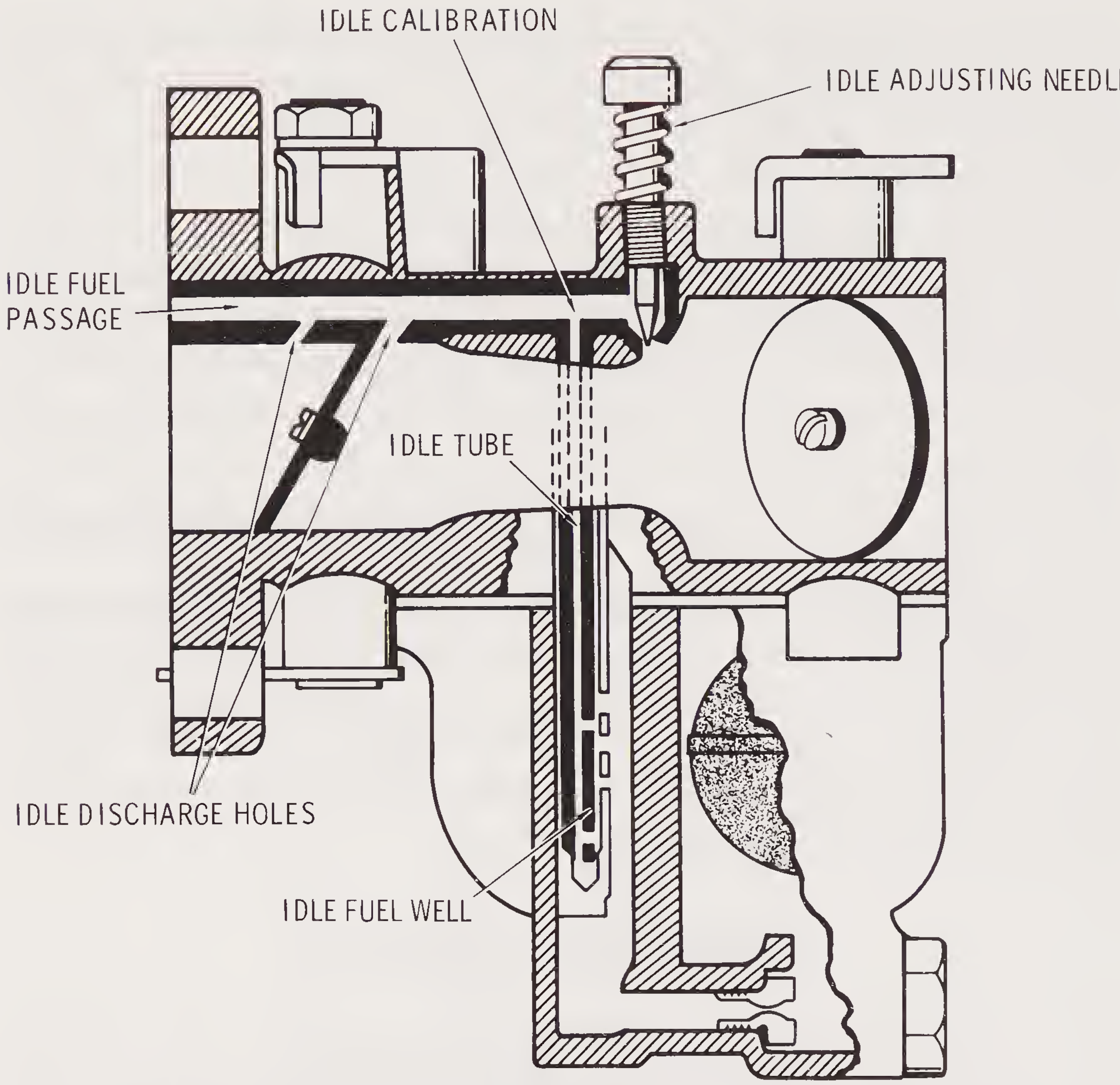



**Fig. 14-13. Typical side-draft carburetor used on small engine.**

satisfactorily handle all of the varied conditions that a carburetor must meet, the other four circuits are necessary. The function of the various circuits, together with a detailed description, will be provided on the following pages.

The *float circuit* maintains the correct level of fuel in the carburetor fuel bowl at all times. Proper float level together with proper venting of the bowl to the atmosphere assures availability of the correct amount of fuel to the other circuits.

The *low-speed*, or idle, circuit delivers the proper mixture of air and fuel when the throttle is practically closed. In some carburetors, it continues to function throughout the entire speed range, whereas in others it merely overlaps the high-speed circuit through a short range. The circuit delivers fuel from the bowl to a point below the throttle valve.

The *main metering*, or high-speed, circuit meters and delivers the proper air-fuel mixture in the range above the low-speed circuit. This circuit delivers fuel from the bowl to the venturi. The *pump circuit* quickly provides a measured supply of fuel necessary for sudden acceleration. The *choke circuit* provides a method of enriching the air-fuel mixture when starting and warming up a cold engine.

## Float Circuit

The float circuits on all carburetors are practically the same. The float mechanism consists essentially of a float and a vent to maintain fuel at a predetermined height in the fuel chamber.

*In operation*, fuel enters the carburetor at the gasoline connection and flows through the needle valve seat into the float chamber. When the fuel reaches the prescribed level in the float chamber, the float presses the needle valve against its seat to shut off the flow of fuel. Thereafter, the fuel is maintained at the prescribed level by opening and closing the needle valve as required.

The float is usually hinged on a fulcrum that is retained in the float bowl by a pin as noted in Fig. 14-14. The float chamber is

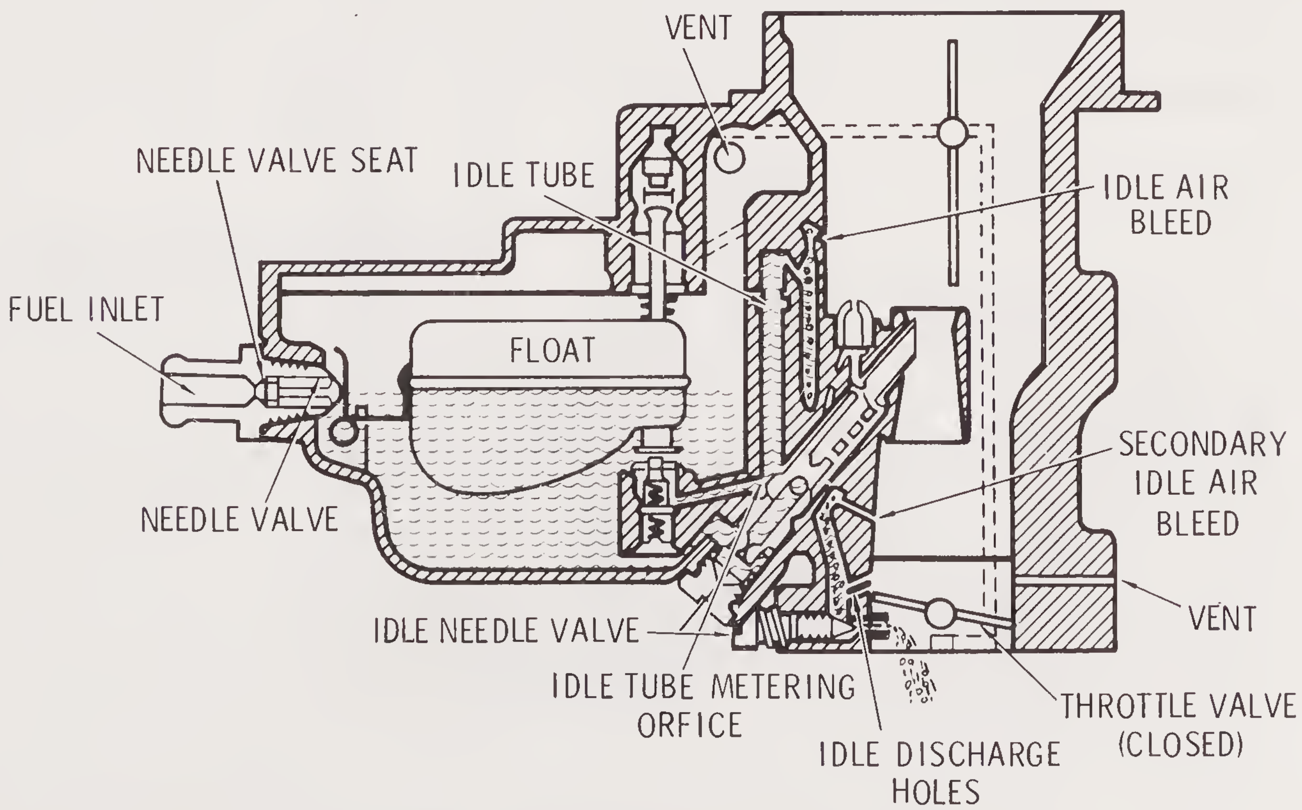



**Fig. 14-14. Float and idle system.**

vented externally through a port in the air horn to allow fuel to be smoothly withdrawn through the various systems.

## Low-Speed Circuit

The low-speed, or idle, circuit does not vary in any considerable extent in construction; some carburetors may, however, have economizer tubes incorporated in its general makeup. The low-speed circuit is necessary because when the throttle valve is almost closed there will be very little air passing through the venturi; that is, the difference in pressure between the bowl and the venturi will not be great enough to cause fuel to enter the throat from the main nozzle.

*In operation*, fuel flows from the float chamber through the main metering jet and up through the idle tube, which meters the fuel. From the idle tube it flows through a connecting channel where air from the idle air bleeder is mixed with it so that a mixture of air and fuel passes down the idle channel to the idle discharge holes. See Fig. 14-15.

On idle or closed-throttle operation, the air-fuel mixture is drawn only from the lower, or primary, idle discharge hole due to high suction at this point. As the throttle valve is opened, suction

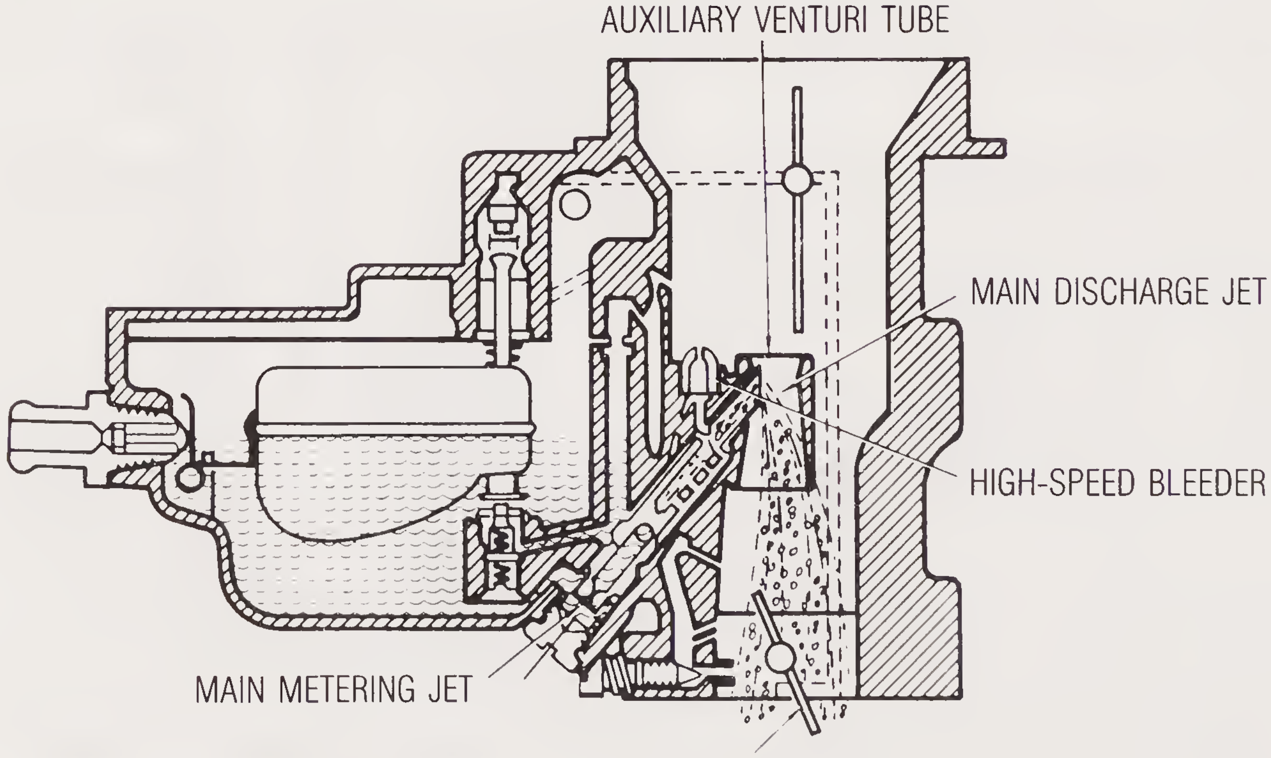



**Fig. 14-15. Carburetor main metering circuit.**

is also placed on the upper, or secondary, idle discharge holes to feed additional fuel.

Fuel supplied through the idle discharge holes begins to diminish when the throttle valve is opened to the point where the main metering system begins to supply fuel, until a throttle position is reached where the idle system ceases to function. The idle needle valve controls the quantity of fuel that is supplied through the primary idle discharge hole, thereby affecting the final air-fuel ratio supplied to the engine while the idle system is in operation.

## Main Metering System

The main metering system controls the flow of fuel during the intermediate or part throttle position. *In operation,* the fuel flows from the float chamber into the main metering jet and then into the base of the main discharge jet. Air is bled through the high-speed bleeder into the main discharge jet so that the mixture of air and fuel is discharged from the main discharge jet into the carburetor. See Fig. 14-15.

The main dicharge nozzle is designed so that if any vapor bubbles are formed in the hot gasoline, the vapors will follow the outside channel around the main discharge nozzle instead of passing through the jet tube. These vapor bubbles escape through the dome-shaped high-speed bleeder and thereby reduce percolating troubles.

## High-Speed Circuit

The high-speed circuit is often termed the high-speed enrichment circuit. Its purpose is to provide additional fuel at wide-open and near-wide-open throttle under heavy load. The additional enrichment provides extra power at the expense of fuel economy. It is operated by vacuum or a mechanical linkage or a combination of both. Carburetors equipped with metering rods usually accomplish high-speed enrichment without additional circuits by providing a method of lifting the tapered metering rod well out of the main jet, allowing additional fuel flow. Carburetors not equipped with metering rods usually incorporate an enrichment or power valve that allows fuel to bypass the main jet and enter the discharge nozzle.

## Accelerator Pump Circuit

The pump circuit is usually mechanically operated and varies in construction, depending on the type of carburetor, from a spring-loaded piston with a mechanical release to a direct-acting asembly. This circuit is basically designed to fill in the gap in carburetor operation when the throttle is opened quickly.

The most widely used construction consists of a pump cylinder, a plunger mechanically actuated by a lever mounted on a throttle shaft, an intake check valve located in the bottom of the pump cylinder, a discharge check valve, and an accelerating jet to meter the amount of fuel used.

As previously noted, the pump circuit provides for smooth and rapid acceleration by means of an extra quantity of fuel when the throttle valve is suddenly opened. This is accomplished by operation of the accelerating pump piston (Fig. 14-16), which is directly connected to the throttle valve by means of a rod and pump lever.

When the throttle is closed, the pump piston moves up and draws a supply of fuel from the float chamber through the inlet

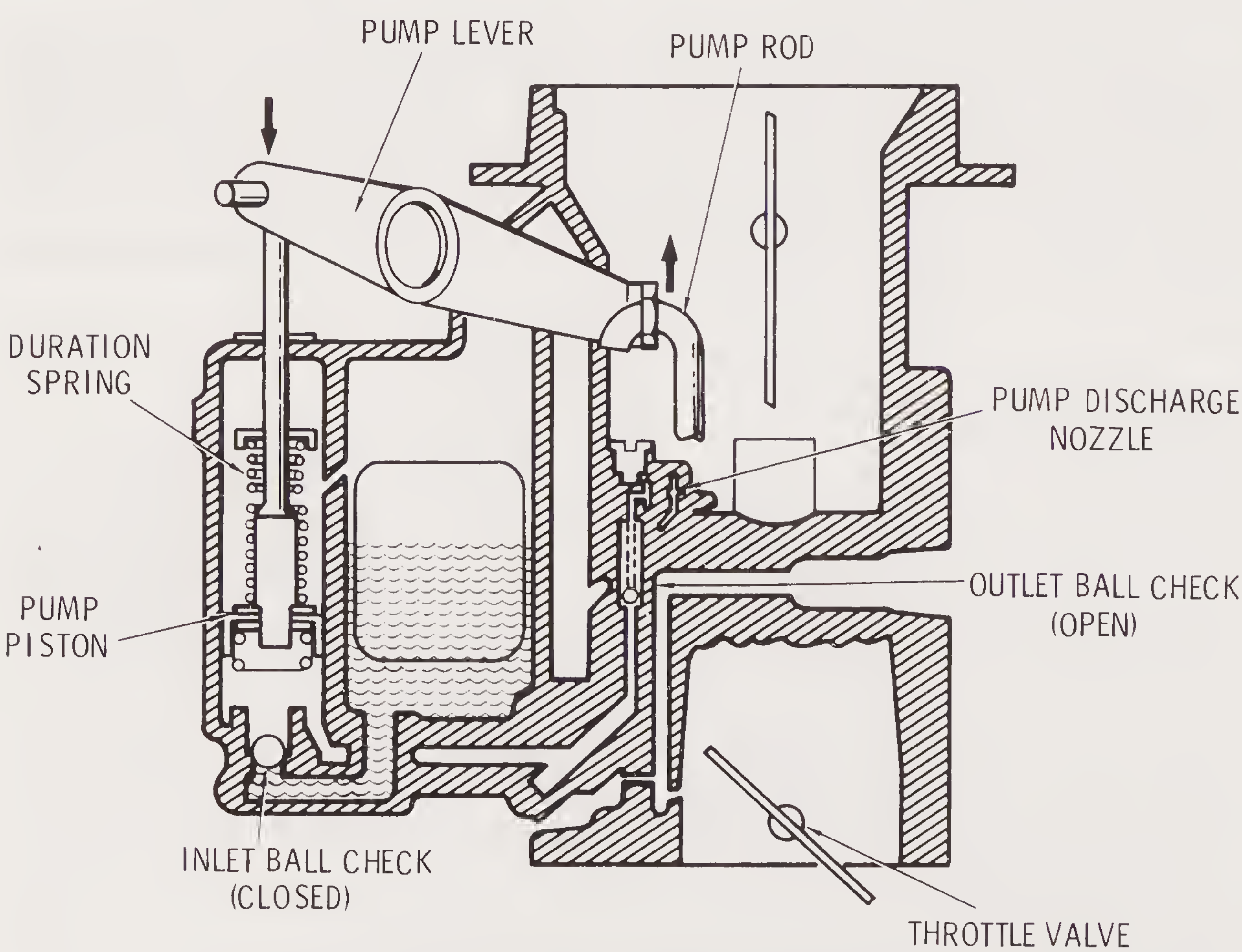



**Fig. 14-16. Accelerator pump circuit.**

check valve into the pump cylinder. When the throttle valve is opened, the piston on its downward stroke exerts pressure on the fuel, which closes the inlet check valve, opens the outlet check valve and discharges a metered quantity of fuel through the pump discharge nozzle. This, however, occurs only momentarily during the accelerating period, since the pump duration spring provides a follow-up action so that the fuel discharge is carried out over a brief period of time.

When the throttle is held in a fixed position, the pressure on the fuel in the pump cylinder decreases sufficiently so that the outlet check valve closes and fuel ceases to discharge from the pump nozzle. With the throttle held in a fixed position, the fuel flows only through the idle or main metering system as previously described.

## Choke System

When a cold engine is being started, much of the fuel discharged by the carburetor is unable to vaporize during its travel to the combustion chamber until sufficient heat is developed in the intake manifold to maintain a homogeneous mixture for efficient combustion. Therefore, a much larger quantity of fuel must be supplied to compensate for this lack of vaporization when starting and operating a cold engine.

To compensate for this deficiency, an automatic choke has been provided. The automatic choke not only controls the air-fuel ratio for quick starting at any temperature, but also provides the proper amount of choking to enrich the fuel mixture for all conditions of engine operation during the engine warm-up period.

The *automatic choke* is often an integral part of the carburetor and consists of a bimetal thermostatic spring and a vacuum piston which opposes the action of the spring. The spring is connected to the choke valve in such a manner as to close the valve when the spring is cold. The vacuum piston tends to open the choke valve a small amount when the engine starts to run and produces a vacuum. See Fig. 14-17.

Therefore, under varying load conditions during the warm-up period, the position of the choke valve will be changed by operation of the vacuum piston working against the thermostatic spring, and

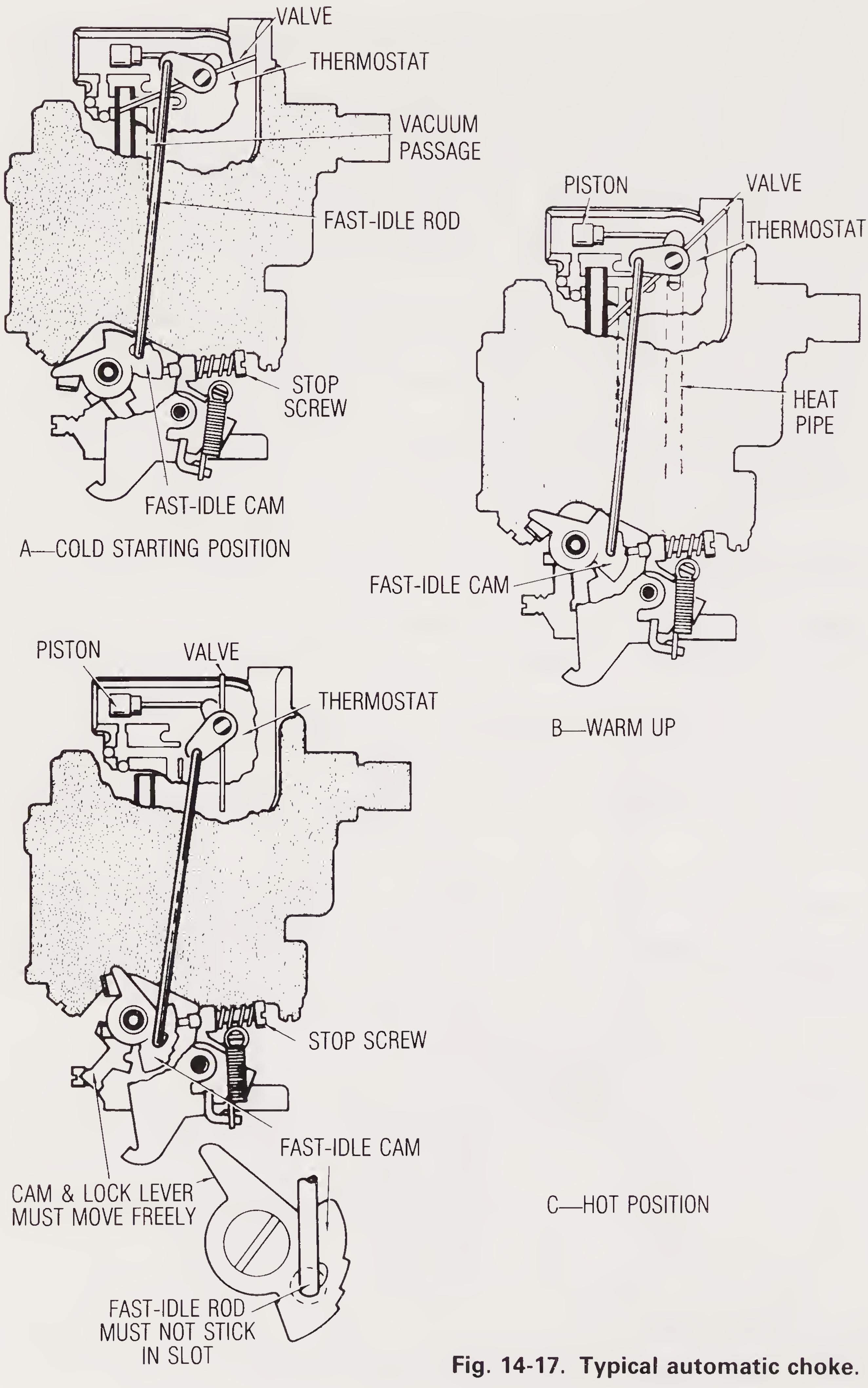



**Fig. 14-17. Typical automatic choke.**

by the air velocity in the air horn. Hot air from the exhaust manifold is directed to the thermostatic spring so that the spring loses its tension as the engine is heated. This permits the choke to open gradually, and after it reaches full-open position, it is held open by the action of the intake manifold on the piston.

## ELECTRONICALLY CONTROLLED CARBURETORS

Many modern automobile manufacturers are utilizing electronically controlled carburetors. This type of carburetor is the result of integrating the sophisticated electronics used in electronic fuel injection with the basic carburetor. The primary difference between a basic carburetor and an electronic carburetor is the addition of an electrically operated device called a fuel solenoid. The complete electronic system includes the same components used with electronic fuel injection.

The fuel solenoid is an electronically controlled valve used to regulate the amount of fuel delivered to the engine through the main metering circuit. Two basic types of electronically controlled carburetors are used today. The first type uses the fuel control solenoid to operate metering rods controlling fuel flow through the main jets. The second type uses a solenoid-controlled power-enrichment valve. In this system, the solenoid opens the enrichment valve to regulate the fuel mixture. The main jets used in the second system are purposely designed small, yielding a lean mixture requiring the fuel solenoid to be active under most conditions.

### Fuel Injection

There are three basic types of fuel injection in use today:

1. Electronic: multi-injector
2. Electronic: mono-injector
3. Mechanical: continuous flow

The two electronic types are very similar and utilize most of the same components. The differentiating characteristic is the number of injectors used.

A typical EFI system control usually contains most of the following units, which are interconnected by an electrical harness:

1. A *manifold absolute pressure sensor* (MAP), or vacuum transducer, that controls the *basic* quantity of fuel at each engine speed.
2. An engine *speed*, or *timing*, *sensor* that determines exactly when each injector valve is to be opened (or, as is generally the case, two or four valves may be opened simultaneously).
3. A *throttle-position switch* that controls the amount of fuel needed for the engine speed called for by the throttle position.
4. *Temperature sensors* for engine coolant and intake air that vary the basic fuel quantity in accordance with immediate engine operating temperatures.
5. *An airflow sensor* for determining the volume of air entering the cylinders and controlling the basic quantity of fuel delivered.
6. A *fast-idle valve* that increases the normal (warm-engine) idle speed during periods of cold starting and warm-up. In some systems, an *air solenoid valve* is also used to supplement the fast-idle valve.
7. An *oil-pressure sensor* that closes down the system if oil pressure becomes dangerously low.
8. Finally, a *control unit* (ECU) that converts all the foregoing signals into the pulses that operate the injector valves.

In other (than EFI) systems the functions of a MAP may be accomplished by two units: a *pressure sensor* and a *pressure switch*. There may be more than two temperature sensors (at different engine locations). Also, a *fuel-injection pump*, to which the various system signals are transmitted, may replace the control unit and injector valves and meter fuel directly to injection nozzles.

## ELECTRONIC: MULTIINJECTOR FUEL INJECTION

This system was the first type used and is still popular today. It uses one injector for each cylinder, all connected to a common fuel

rail. Each individual injector has a separate internal solenoid and fuel valve, yet all are connected to one control system. Most multiinjector systems open all the injectors simultaneously once every other revolution of the crankshaft.

## Fuel Injectors

Fuel injector valves are used with fuel injection systems. They are solenoid-operated pintle valves with integral fine-mist nozzles that project into the intake manifold above the respective intake ports. Each valve is operated by a pulsed signal from the control unit (ECU), which opens the valve for the proper time interval (pulse width) to deliver the amount of fuel determined by the ECU. Fuel for the valves of an engine (one valve for each cylinder) is delivered by the *fuel rail*, which is attached to the tops of the valve bodies and in which fuel is kept at a constant, predetermined pressure (so that the opening time of each valve is the only determinate of the amount of fuel injected at each valve opening). Generally, with V-type engines, the fuel rail is divided into two parts, each of which serves half the total number of valves (i.e., for cylinders 1, 2, 7, 8 and 3, 4, 5, 6). See Fig. 14-18. The two parts are so assembled that one pressure regulator, installed in the complete assembly, serves both halves.

**Note:** In systems not having a computerized control unit the injectors do not have valves; they are simply nozzles.

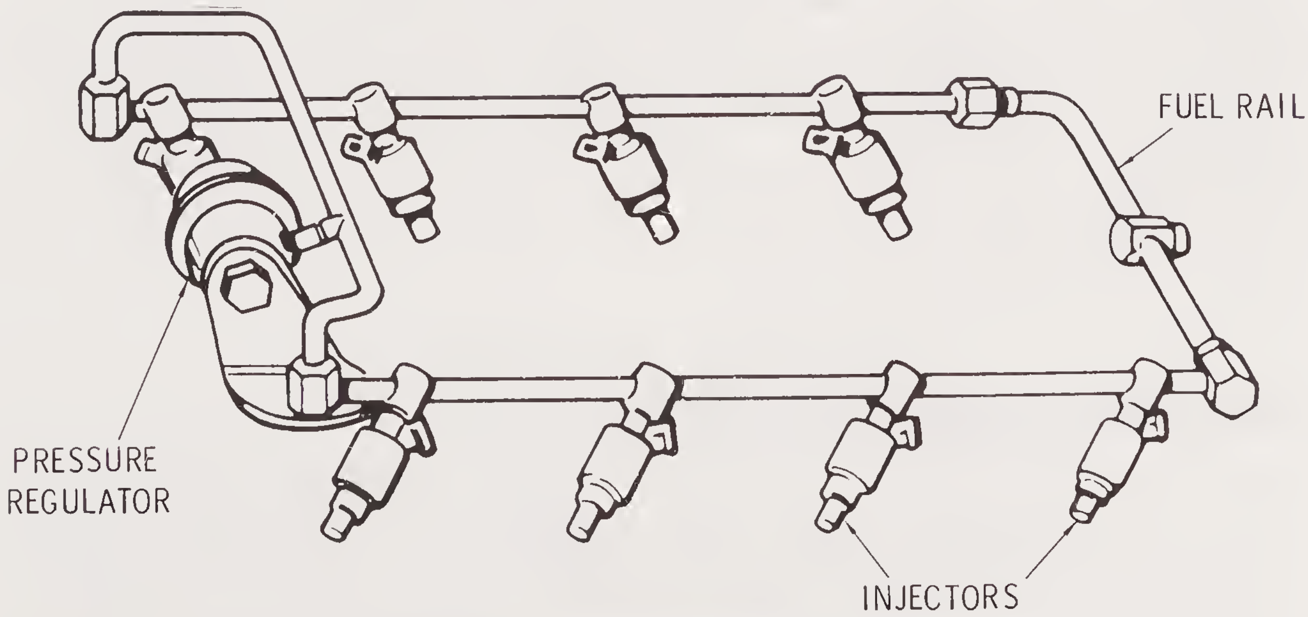



**Fig. 14-18. Fuel rails and injector system.**

## Fuel Pumps

Two electric fuel pumps are usually used. The first, located in the fuel tank, is generally a diaphragm-type booster pump (Chapter 13) that is integral with the fuel gauge and a simple, replaceable-element filter. The second, located somewhere in the fuel line ahead of the pressure regulator, is usually a roller-vane pump driven by a 12-volt motor, and is designed to produce a constant displacement. This (second) pump has a check (one-way pressure-opened) valve at the output side that prevents backflow to maintain pressure in the line when the pump is not operating. In general, pumps have built-in design factors that cannot be altered by service procedures.

## Fuel Pressure Regulator

Because the (second, above) fuel pump operates continuously at maximum output, regardless of engine speed, load, etc., the engine seldom requires all the fuel the pump makes available. It is the function of the pressure regulator to return excess fuel through a bypass line back to the tank, and thus to maintain a constant pressure in the fuel rail. The regulator contains two chambers separated by a spring-loaded diaphragm. One (air) chamber is connected by hose with the throttle body and is thereby subjected to an air pressure that is determined by the intake-manifold pressure and that, in turn, controls the position of the diaphragm. The diaphragm is mechanically connected with a valve in the other (fuel) chamber so that its position determines the amount of fuel bypassed to the tank. Thus, it is the differential between the diaphragm spring and the intake-manifold pressure that controls the percentage of bypassed fuel, and very accurately maintains a constant, predetermined pressure in the fuel rail. Generally, this differential is factory set and there is no manual adjustment.

## Electronic Control Unit (ECU)

This may be an analog or a digital computer (with electronic circuits) that is preprogrammed by the manufacturer to "accept" certain signals from the various sensors of the system and to "translate" these into a pulsed signal for operation of the fuel-injection valves.

See Fig. 14-19. It is generally contained within a compact housing designed for mounting as desired and for connection, by a designed electrical harness, to the other components of a system. This is a nonserviceable unit which must be replaced if faulty. It may or may not contain the MAP.

## Manifold Absolute Pressure Sensor (MAP) or Vacuum Transducer

This essential component of any fuel injection system may be incorporated within the control-unit housing or may be a separate unit (mounted where convenient). Its functions are to monitor the intake-manifold pressure through a suction-tube connection to the

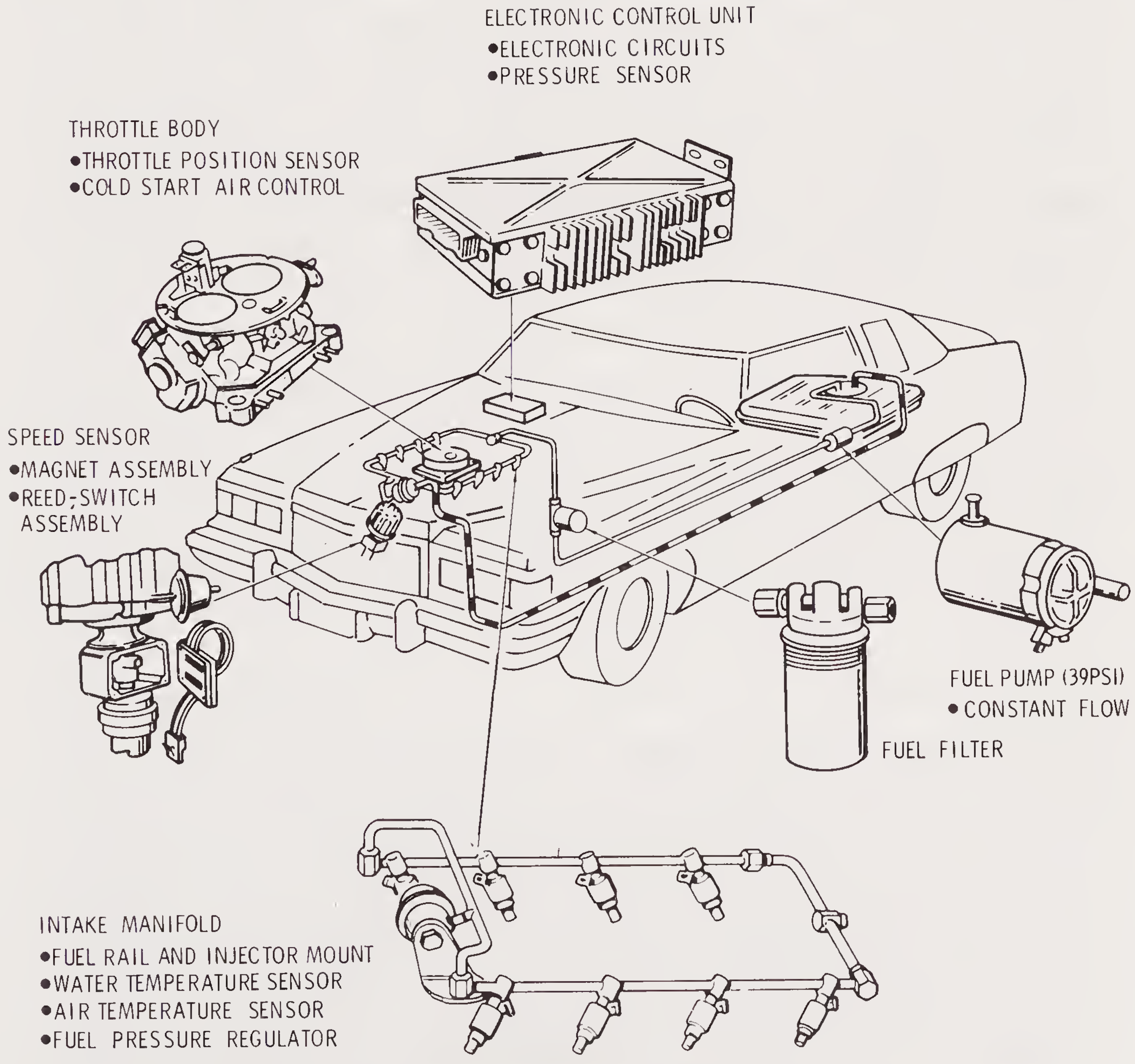



**Fig. 14-19. A typical electronic fuel injector system.**

throttle body and to transmit an electrical impulse to the control unit whereby the duration of injector-valve opening is affected. Because intake-manifold pressure is increased or decreased in relation to engine speed, engine load, barometric pressure and altitude, all these factors determine the "related" signal sent to the control unit. The unit contains an air-pressure diaphragm that mechanically operates an electronic control through which the strength of the transmitted impulse is varied.

## Pressure Sensor and Switch

Together these function in the same manner as a MAP (preceding). The pressure sensor, which may be mounted in the throttle body, "senses" the manifold pressure and "signals" the switch (mounted elsewhere). The switch electronically measures the differential between the manifold pressure (signals from the sensor) and the ambient air pressure, and transmits signals to the control unit.

The speed sensor is used with EFI systems, and the function of this component is to time the fuel injections both in relation to the firing orders of the cylinders and the speed of the engine. Therefore, the speed sensor operates with regard to the fuel-injection system in exactly the same manner that the distributor operates with regard to the ignition system—and, to correlate the two, it is actually housed within the distributor. Some systems use an additional set of points mounted within the ignition distributor, or may include an additional distributor solely for the fuel injection system.

Newer systems associated with electronic ignition utilize the basic signal emitted by the ignition distributor. Others use a rotor mounted on (and rotating with) the distributor shaft with two permanent magnets. There are also two electrically magnetic reed switches that are mounted on a plastic "sensor" housing within the distributor body. Rotation of the rotor magnet within the field of the reed switches creates timed electrical currents in the switch circuits, which conduct the current (through the ECU harness) to the control unit. The position of the rotor on the distributor shaft and the speed of shaft rotation determine, respectively, the instant and frequency of the electrical impulses sent to the control unit—and these are subject to the identical factors (distributor advance and speed) that affect the ignition timing. See Fig. 14-20.

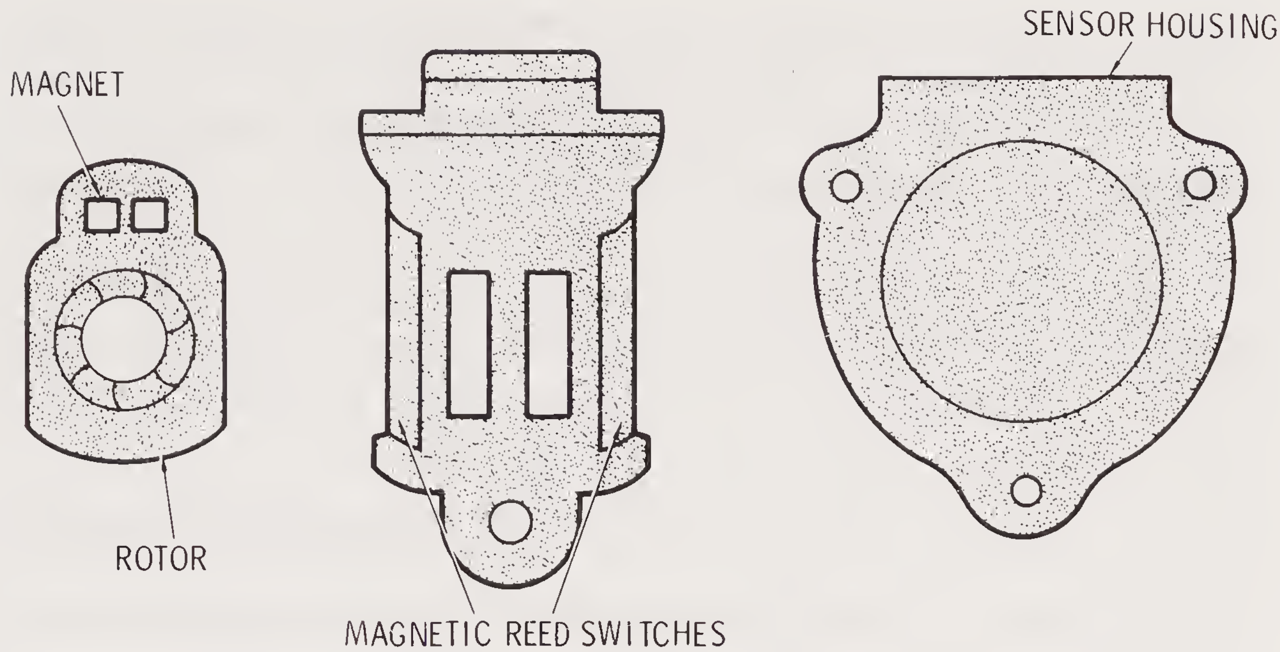



**Fig. 14-20. Reed-type speed sensor.**

## Throttle-Position Switch

Like the MAP, this is a mechanically operated electronic device. The unit is mounted on the throttle body and operated by the accelerator linkage. It monitors both the movement and the position of the throttle shaft and transmits appropriate signals to the control unit.

## Temperature Sensors

These, again, are electronic devices operated by a bimetal spring or strip. Each operates independently, sensing temperature at key points of the engine and transmitting signals to the control unit.

## Fast-Idle Valve

There is an adjustable setscrew on the throttle body for normal (warmed-engine) idle speed, but a faster idle adjustment (equivalent to choking) is needed for starting and warm-up. The adjustment provided is a valve that admits additional air (and, therefore, also additional fuel) to temporarily increase the flow of the air-fuel mixture to the cylinders. This valve is mechanically operated by a thermal (bimetal) element that normally holds the valve open. Engine heat or an integral electric heating element serves to warm the bimetal element and close the valve. Turned on by the ignition

switch, this heater requires more or less time to reach its "valve-closed" temperature, depending on the ambient air temperature and the heat from the running engine. Once this temperature is reached, the valve remains closed and no longer affects system operation. See Fig. 14-21.

The valve may be mounted in the throttle body or in the air intake from the air cleaner. In the latter case, an air solenoid valve may be used to supplement its operation. The pintle-type solenoid valve controls an auxiliary air-intake passage and is operated by the control unit in response to signals from the coolant-temperature sensor. It serves to introduce engine cooling-water temperature as a second factor in determining the length of the warm-up period.

## Oil-Pressure Sensor

This oil-pressure-sensitive, diaphragm-operated unit is otherwise similar to the preceding sensors. Its function is to shut off the fuel supply (kill the engine) if oil pressure drops below a safe level.

## Oxygen Sensor

Most modern fuel injection systems utilize a device termed an $O_2$ (for oxygen) sensor. This device is mounted so that it extends into the front portion of the exhaust system. In operation, the oxygen sensor produces a very small voltage that varies in accordance with the amount of unused oxygen present in the exhaust gases. Obviously, the leaner the mixture, the more unused oxygen emitted in the exhaust. The different voltage levels are interpreted by the engine control unit (ECU), which calibrates the fuel mixture accordingly. Operation of the electronic system in accordance with

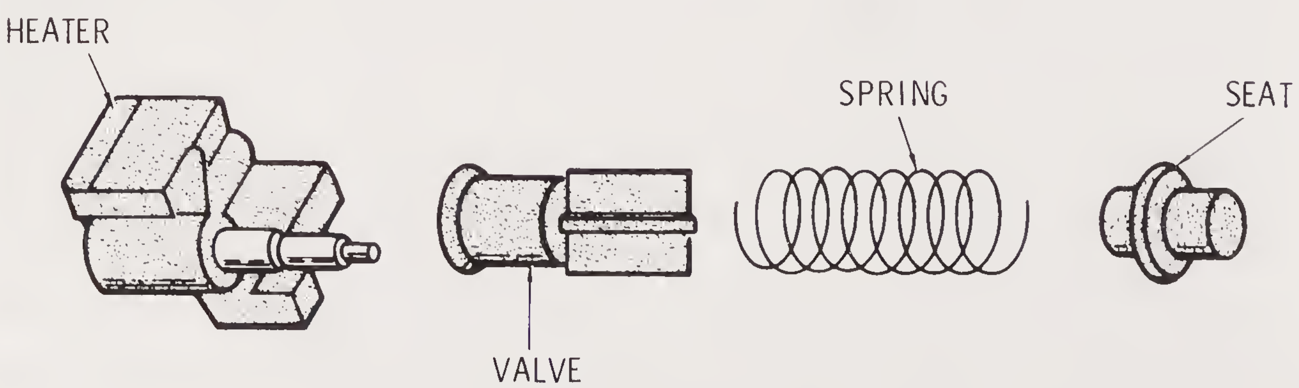



**Fig. 14-21. Parts of fast-idle valve.**

signals provided by the oxygen sensor is known as *closed-loop operation,* or *mode.* Since the oxygen sensor is designed to operate within extreme heat (above 600°F) and is unable to differentiate between the increase of exhaust oxygen produced by a misfiring cylinder or an air leak, an override system must be included. When the engine is cold (first started) or oxygen levels become extreme, the system exhaust automatically switches to *open-loop mode* and disregards the oxygen sensor.

## Vehicle Speed Sensor

This unit is located behind the speedometer in some fuel injection systems. It signals the ECU of vehicle speed, used to aid in determining engine loading.

## Air Temperature Sensor

Many fuel injection systems use an electronic sensor known as a thermistor to monitor the temperature of incoming air.

## Clear Flood

Some fuel injection systems automatically limit fuel delivery if the engine is operating below 600 rpm and the throttle is held wide open. This enables the operator to clear and start a flooded engine.

## Fuel Injection Pump

Used only on some European-designed engines, this unit embodies all the functions of a control unit, injector valves, and all other preceding controls except for temperature sensors and a special fuel-injection starting valve (mounted in the throttle body). The pump is driven by the engine camshaft and utilizes both manifold pressure (through a section line) and a governor to determine the basic fuel requirements, which are metered by the pump in required amounts to the spray-type injector nozzles. Basic requirements are varied by sensors similar to those already discussed. A number of extremely sensitive manual adjustments are required.

## ELECTRONIC: MONOINJECTOR FUEL INJECTION

The monoinjector system is very similar and may utilize the same components as the multiinjector system. It has become the most popular system used on newer automotive engines because of the simplicity and superior fuel atomization provided by using only one fuel injector. In a monojet system, the ECU and sensor sytems are used to control the fuel delivered by one centrally mounted injector. The injector is typically operated synchronously, meaning one fuel pulse for each cylinder intake during normal operation, and nonsynchronously during start and high-speed operation. See Fig. 14-22.

## MECHANICAL FUEL INJECTION

Mechanical fuel injection is inherently simpler than electronically controlled fuel injection. No ECU or electronic sensors are utilized; only the basic injector nozzles for producing a fine spray and fuel

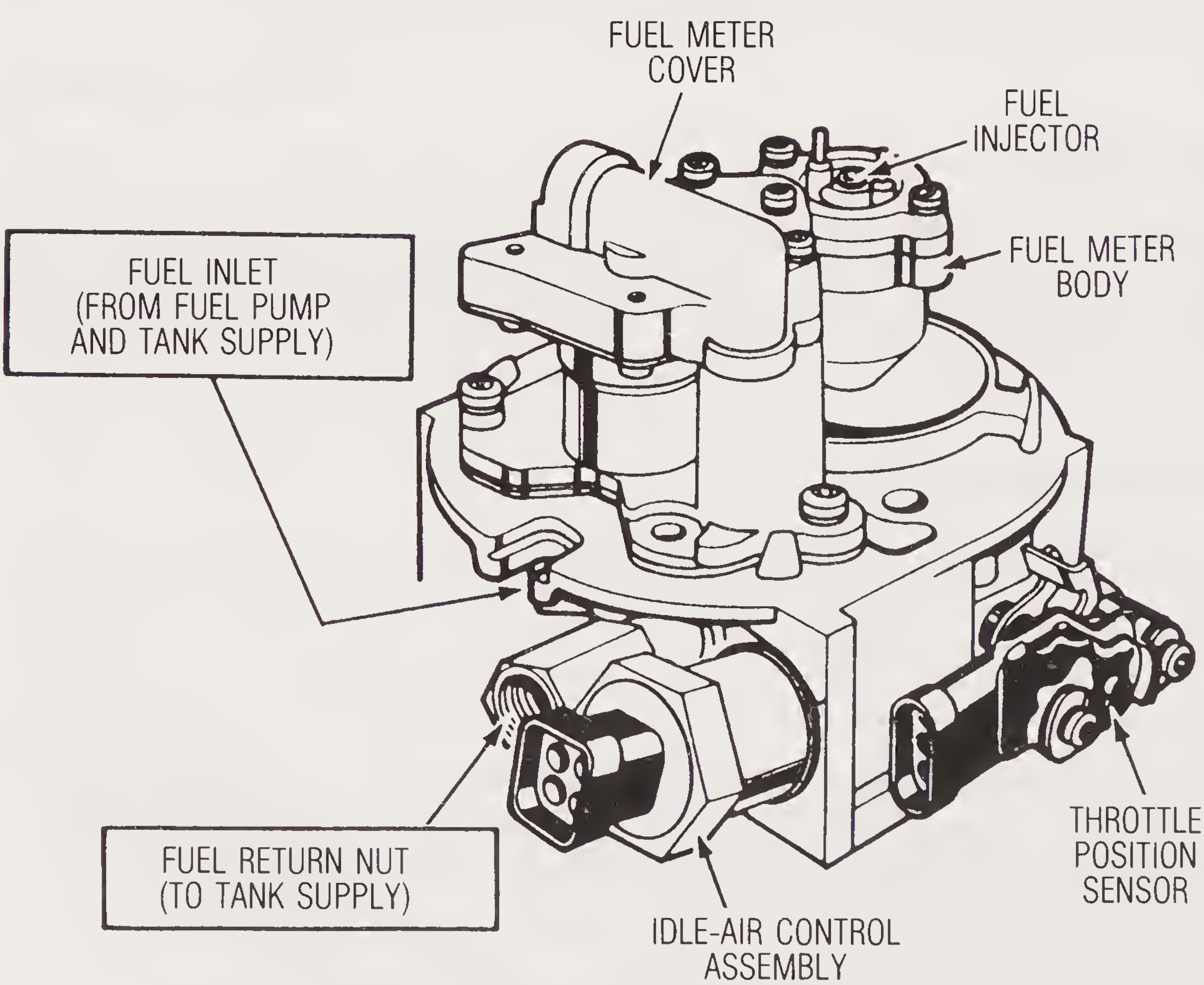



**Fig. 14-22. Throttle-body-style monoinjector fuel injection.**

pump are comparable with those used in electronic systems. The primary difference in operation is the uninterrupted flow of fuel emitted by the injectors during engine operation as contrasted to the pulsed fuel flow of the electronic systems. See Fig. 14-23.

### Fuel Accumulator

The fuel accumulator is added between the fuel pump and fuel distributor to protect against sudden pressure surges and vapor lock.

### Cold Start Valve

The cold start valve injects additional fuel into the air supply for starting the engine. It receives electrical power from the starter and is controlled by engine and air temperature.

### Fuel Distributor

The fuel distributor takes the place of the ECU in a mechanical fuel injection system. It is the primary control of fuel mixture admitted to the engine cylinders. Inside the fuel distributor a sensor plate connected to the fuel-metering unit controls fuel flow to match airflow.

### Control Pressure Regulator

The control pressure regulator is the secondary fuel mixture control and senses engine block and oil temperature. At cold temperatures, the control pressure regulator increases fuel pressure to cause the needed enrichment of the fuel mixture.

To control airflow to the engine, all fuel injection systems rely on some type of throttle similar to the type found in carburetors. Most fuel injector systems utilize some method for supplying additional air to the engine during cold idle operation.

### Auxiliary Air Regulator

The auxiliary air regulator is operated by engine heat and allows air to bypass the throttle to increase cold idle speed. The extra airflow is automatically compensated for by the normal sensor system.

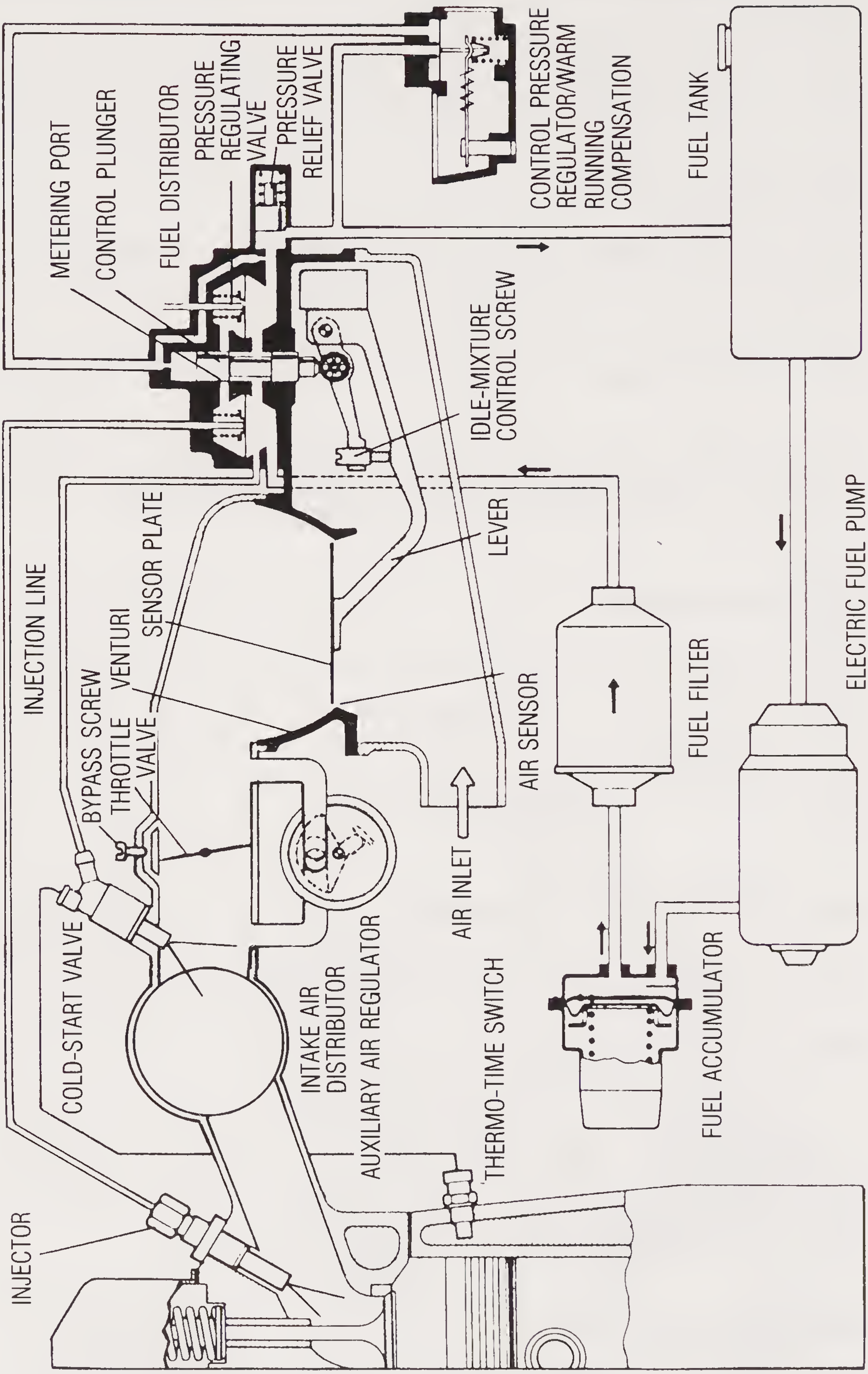



**Fig. 14-23. Continuous-flow mechanical fuel injection.**

# ENGINE SPEED GOVERNORS

Governors are used on engines to regulate maximum speed and to prevent excessive wear. By experiment it has been found that the rate of wear in an engine increases as the square of its rpm. In the higher speed ranges, therefore, an increase of a few hundred revolutions per minute will result in a greatly disproportionate amount of wear.

Governors are classified according to their method of operation as:

1. Centrifugal.
2. Vacuum.
3. Air.

## Centrifugal Governor

This type of governor operates on mechanical principles, and in its basic form is made up of two weighted arms pivoted on a spindle connected by suitable linkage to the throttle valve.

*In operation*, the centrifugal governor is connected to the engine by means of a flexible drive shaft, driven from the camshaft or an accessory drive of the engine. As the engine and spindle rotate, the spindle weights will tend to fly outward, actuated by centrifugal force, but are retarded by the spring tension. A screw at the end of the spring controls the tension with which the spring holds the weight against the spindle.

It will be noted from the foregoing that as the speed of the engine increases, the weights will tend to fly outward with sufficient force to actuate the throttle valve linkage and close the throttle. As the engine speed decreases, each weight is pulled inward by its spring, and the throttle opening is increased. It is in this manner that the speed of the engine is controlled automatically by a regulation of the throttle opening.

## Vacuum Governor

The vacuum governor still utilizes some type of mechanical device to sense engine speed. This device is used to regulate the amount

of vacuum allowed to the throttle-closing mechanism. The vacuum is used to operate a diaphragm unit that forces the throttle to close against spring pressure regulated by pressure on the accelerator.

The advantage of this system is its load sensitivity. The heavier the load on the engine, the lower the engine vacuum, and the less able the governor will be to close the throttle. Therefore, the engine is allowed to achieve maximum rpm under heavy loads, such as climbing a steep grade, where lower gears make high engine speed necessary, while limiting rpm under light loads, such as normal highway driving, that could be adjusted for by changing to a higher gear or lower vehicle speed.

## Air Governors

This type of governor is used on small air-cooled engines. An air valve known as a vane is mounted in the major cooling airflow. As engine speed increases, the volume and velocity of cooling air is increased, applying additional force to the control vane. The control vane in turn pulls back on the throttle, closing it.

CHAPTER 15

# Fundamental Electricity

A knowledge of electricity is of great importance to mechanics because it enables them to grasp more clearly the operating principles of the various units comprising the electric starting, lighting and ignition systems associated with internal combustion engines.

Many different theories have been advanced as to the true nature of electricity. Presently, however, the *electron theory* is accepted among scientists as the only means by which the nature of electricity can be satisfactorily explained. In general, the electron theory explains how electrical effects are caused by the movement of extremely small particles of electricity known as *electrons*. Thus, it is actually the movement of electrons through a wire or conductor which constitutes the current flow.

A mechanic is more concerned about the applications and uses of electricity than he is about the theoretical principles involved. A general understanding of the behavior of electric currents, however,

is considered necessary for satisfactory work and troubleshooting or repairs of electric units on internal combustion engines.

## OHM'S LAW

Briefly stated, Ohm's law expresses the fixed relationship between the current, voltage and resistance which always exists in an electric circuit. It states that the electrical current in *amperes* passing through a conductor equals the pressure in *volts* divided by the resistance in *ohms*. It is written:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

which is usually written:

$$I = \frac{E}{R}$$

or:

$$R = \frac{E}{I}$$

Similarly:

$$E = I \times R$$

The foregoing formulas are of the utmost importance to any electrical system, since they contain the means whereby *current*, *voltage* and *resistance* in a circuit may be determined. Ohm's law also shows that for a given voltage, the lower the resistance, the larger will be the current; and the higher the resistance, the smaller the current.

**Ques. What is a volt?**

Ans. The unit of electric pressure called electromotive force. It is *that electric pressure which produces a current flow of* **one ampere** *through a resistance of* **one ohm.** See Fig. 15-1.

**Ques. What is an ampere?**

Ans. The unit of electric current. It is *that current caused to flow through a resistance of* **one ohm** *by a pressure of* **one volt.**

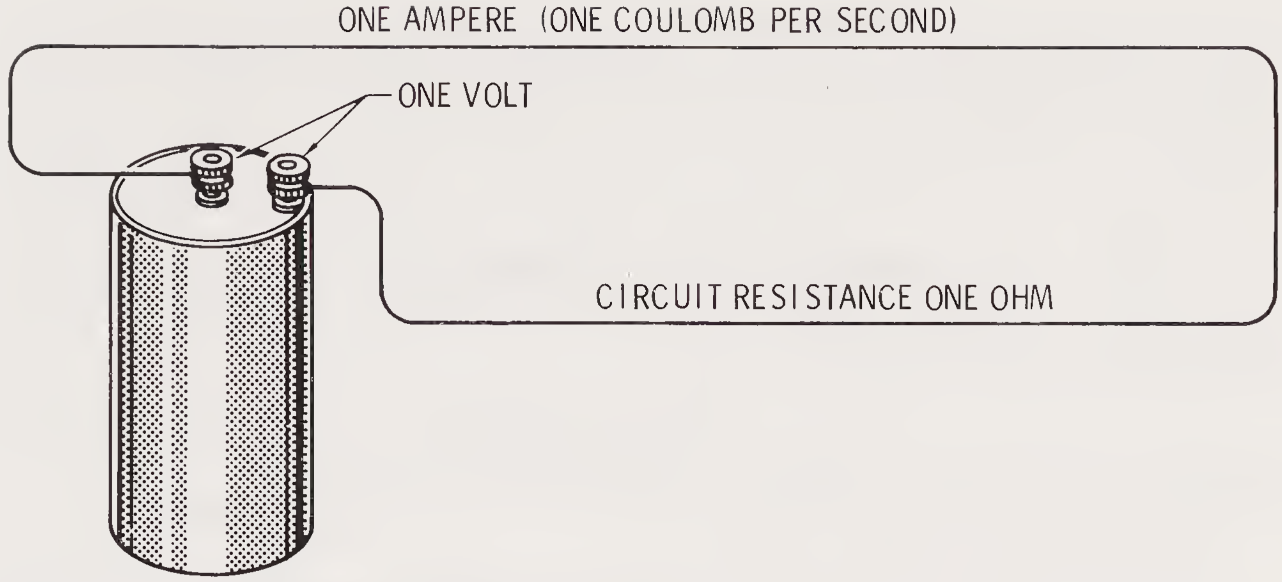



**Fig. 15-1. Simple circuit showing relation between volts, amperes, coulombs and ohms.**

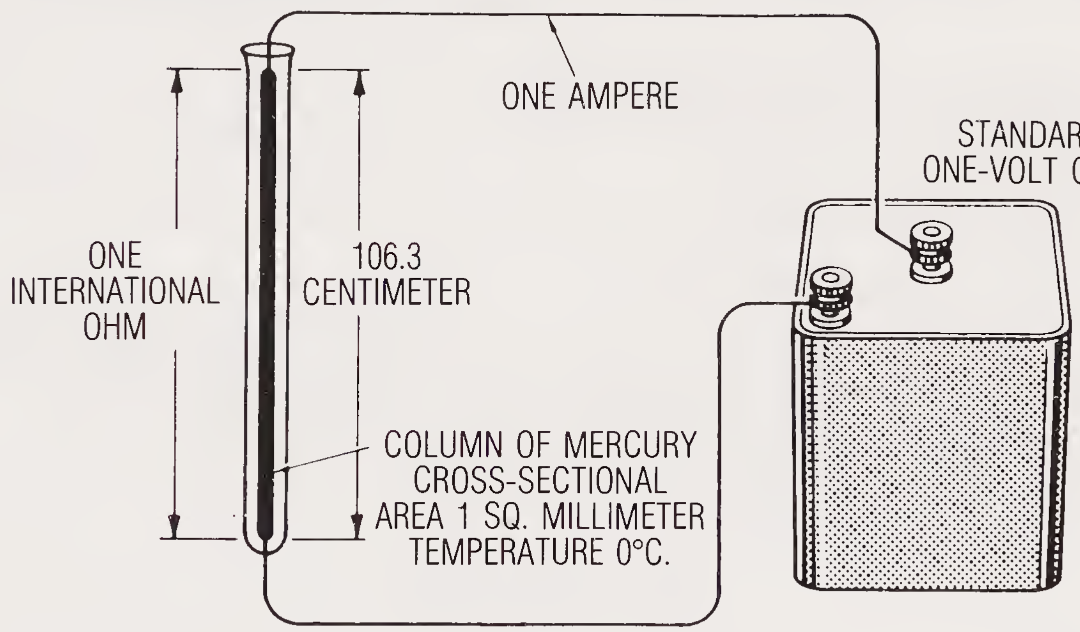



**Fig. 15-2. The ohm.**

**Ques. What is an ohm?**

Ans. The unit of measure used to describe a material's ability to pass an electrical current. The scientific standard is based on a column of pure mercury at 32°F. one square millimeter in area and 106.3 centimeters long. See Fig. 15-2.

**Ques. What is resistance?**

Ans. That property of a substance that opposes the flow of an electric current. Unit, the *ohm.*

**Ques. What is an insulator?**

Ans. A substance that offers tremendous resistance to the passage of an electric current.

**Ques. Name two kinds of wire conductors?**

Ans. Copper wire (low resistance); carbon wire (high resistance.)

## KINDS OF CURRENT

The electric current is said to be:

1. *Direct* when it is of unvarying direction.
2. *Alternating* when it flows rapidly to and fro in opposite directions. See Fig. 15-3.

**Ques. What names are given to low and high voltage currents?**

Ans. *Low-tension* and *high-tension* currents, respectively.

**Ques. What is an insulated circuit?**

Ans. One in which the wires are covered with insulating material to prevent leakage.

**Ques. What is a short circuit?**

Ans. One in which the current returns to the source without passing through a load or doing work. This occurs because the current will always take the path of least resistance.

## MAGNETISM

By definition, *the property some bodies have to attract iron and steel is called magnetism and those bodies having the property are*

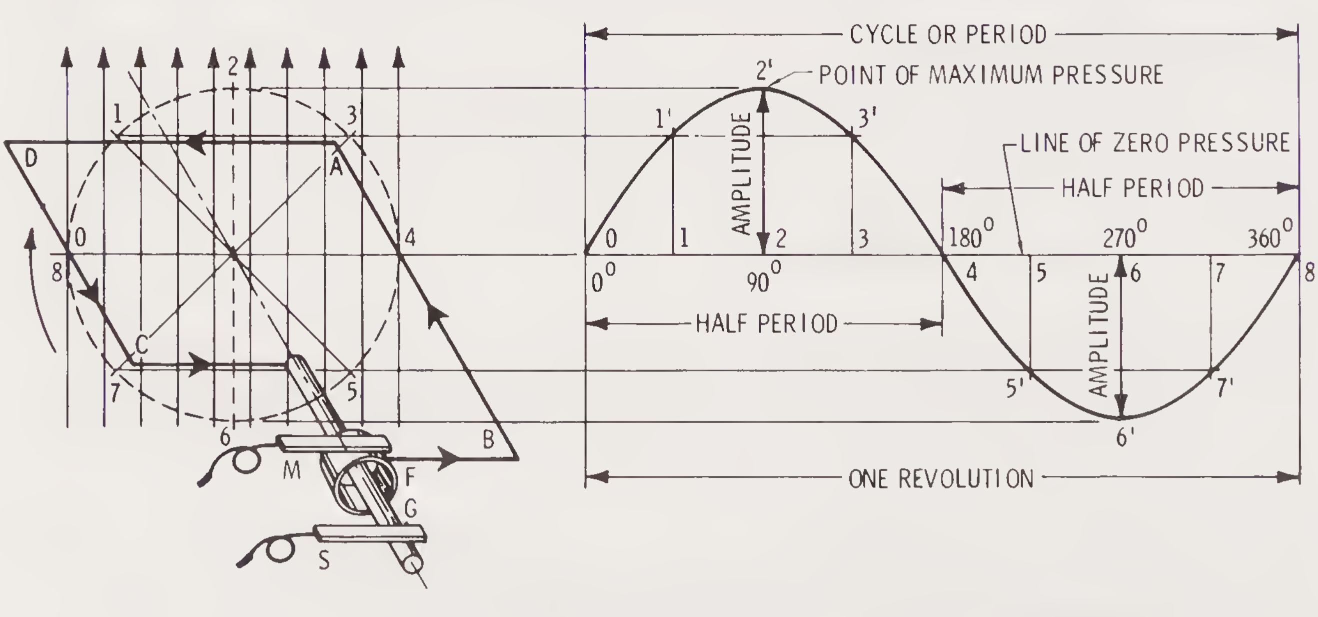



**Fig. 15-3. Alternating current represented by the *sine curve*.**

*called magnets.* Magnets have two opposite kinds of magnetism, or *magnetic poles.* One of these poles tends to move toward the north and the other toward the south. They are accordingly called the *magnetic north* and *south* poles. See Fig. 15-4.

**Ques. What are the two laws relating to the poles?**

Ans. *Unlike* poles *attract* each other; *like* poles *repel* each other.

**Ques. What is a permanent magnet?**

Ans. One made of hard steel and which holds its magnetism almost indefinitely.

**Ques. What is an electromagnet?**

Ans. One made up of an iron core over which are wound a number of turns of insulated wire. See Fig. 15-5.

**Ques. What happens when an electric current flows through the winding?**

Ans. The core becomes magnetized and strong poles are produced.

**Ques. What is a solenoid?**

Ans. A spiral conductor of numerous turns with or without an iron core which forms a magnet when current passes through the coil. The core greatly increases the strength of the solenoid.

**Ques. What is a magnetic field?**

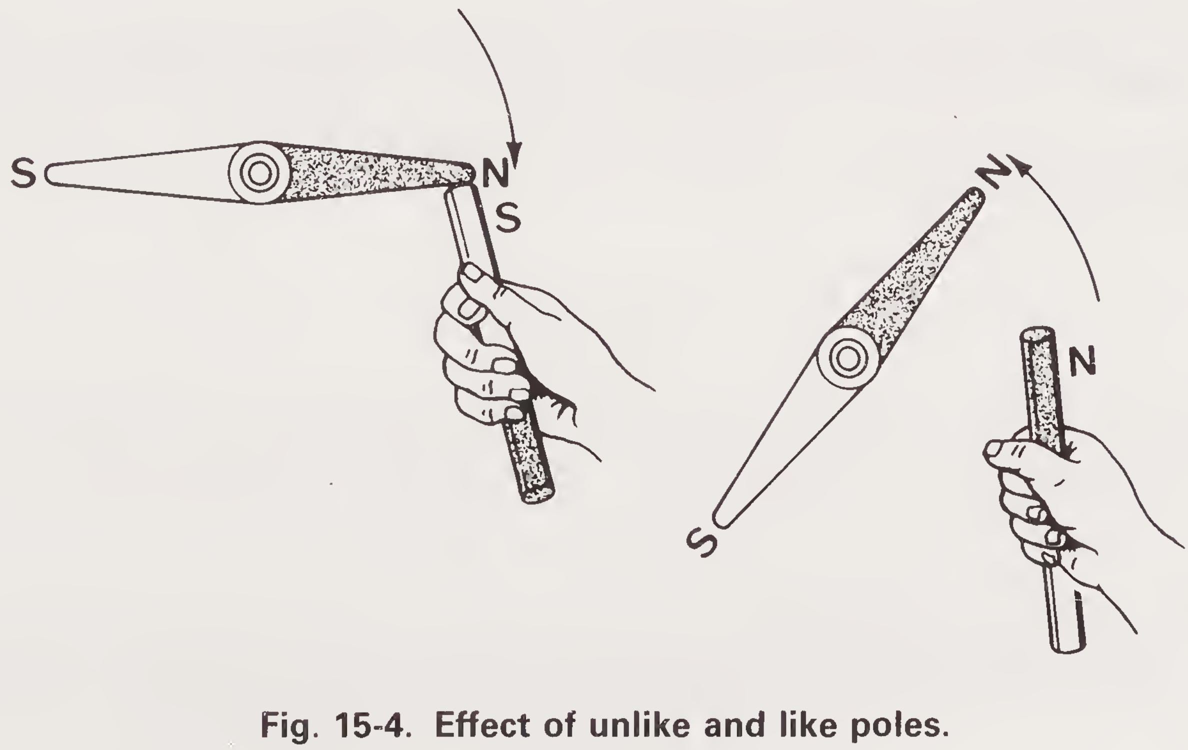



**Fig. 15-4. Effect of unlike and like poles.**

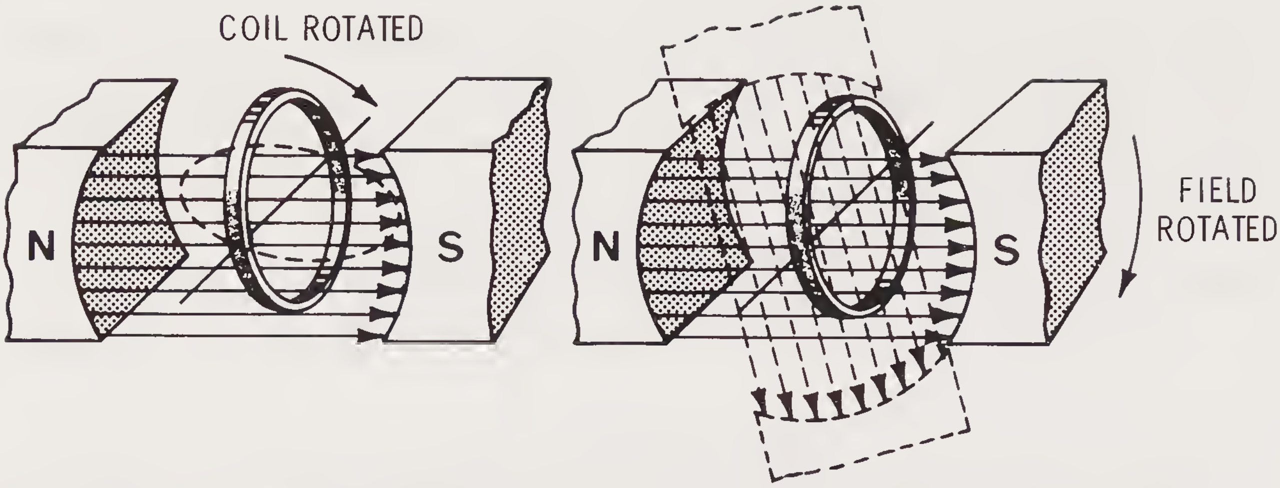



**Fig. 15-5. Examples of electromagnetic induction. Either the coil or the field may be rotated to cut lines of force.**

Ans. The region surrounding a magnet in which the magnetic force acts.

## ELECTROMAGNETIC INDUCTION

By definition, electromagnetic induction is *the tendency of electric currents to flow in a conductor when it is moved in a magnetic field so as to* ***cut*** *lines of magnetic force.* All generators of whatever form are based on this discovery made by Faraday.

**Ques. What are *cut lines of force*?**

Ans. *A conductor forming part of an electric circuit* ***cuts*** *lines of force when it is moved across a magnetic field in such manner as to* ***alter*** *the number of magnetic lines of force embraced by the circuit.* The current is called the *induced current* and that part of the wire moved in the magnetic field the *inductor*, often mistakenly called the conductor.

## CELLS

By definition, a cell is *a device for producing electricity by placing two dissimilar metal plates in a material called the electrolyte.* The two dissimilar plates are called the *elements.*

**Ques. What is a battery?**

Ans. Two or more cells joined together so as to form a single unit.

**Ques. What is the difference between *primary* cells and *secondary* cells?**

Ans. Cells are said to be *primary* when they produce a current immediately after production; *secondary* when they first require a charge from an external source, storing up a current supply. An assembly of secondary cells joined together is known as a storage battery.

## CELL CIRCUITS

There are three methods of connecting cells: (1) in *series* (Fig. 15-6); (2) in *parallel* (Fig. 15-7); and (3) *in series-parallel*, as shown in Fig. 15-8.

## PRIMARY INDUCTION COILS

This type of coil consists of *a long iron core wound with a considerable length of a low-resistance insulated copper wire.* Its operation is due to *self-induction.* See Fig. 15-9.

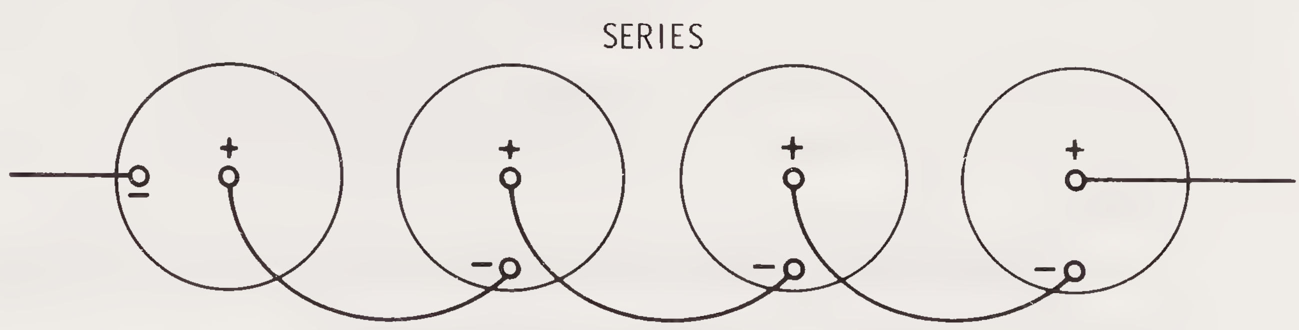



**Fig. 15-6. Series battery connection. Voltage of battery equals product of the voltage of a single cell multiplied by the number of cells.**

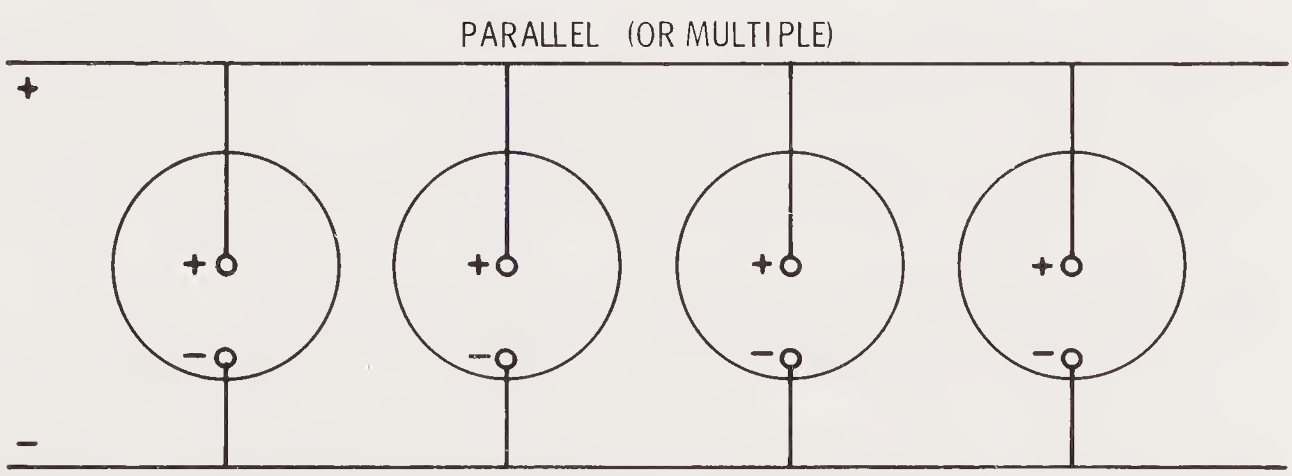



**Fig. 15-7. Parallel battery connection. Voltage of battery equals voltage of a single cell; the current is equal to the amperage of a single cell multiplied by the number of cells.**

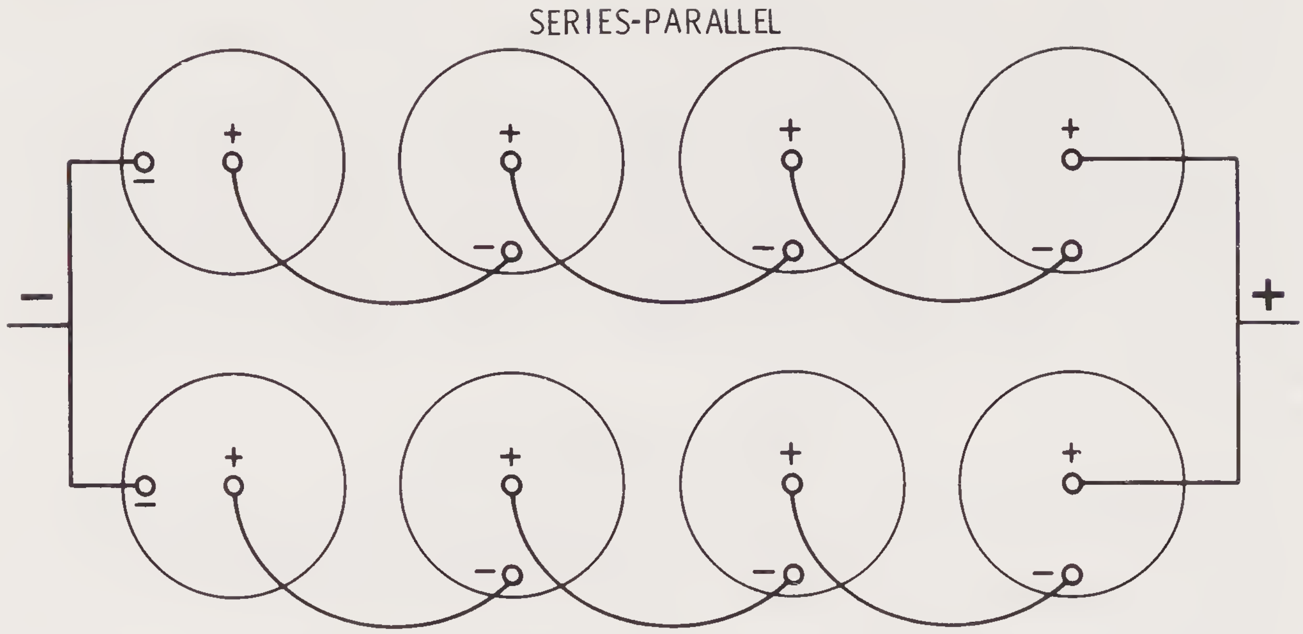



**Fig. 15-8. Series-parallel battery connection.**

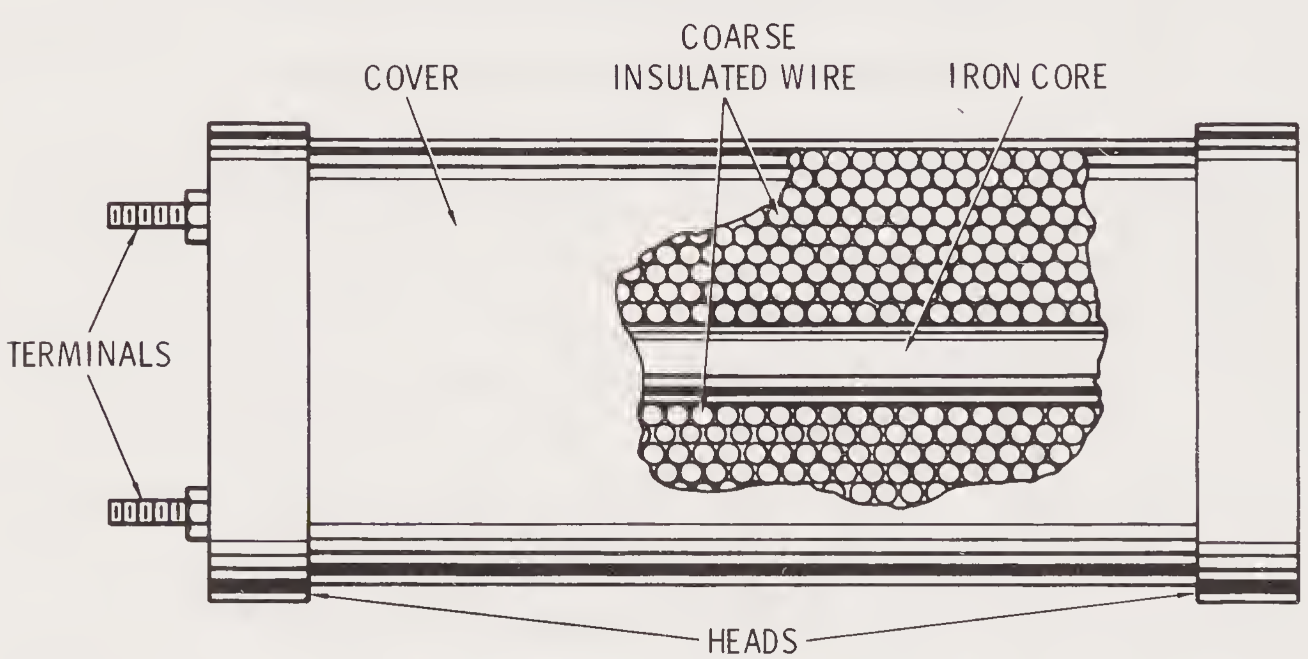



**Fig. 15-9. Primary induction coil used for ignition.**

**Ques. What is self induction?**

Ans. The property of an electric current by virtue of which *it tends to* ***resist*** *any change in its* ***rate*** *of flow.* Self-induction becomes especially marked when the current passes through a primary coil.

**Ques. How is the self-induction brought into action?**

Ans. By making and breaking the circuit connected to the source.

**Ques. What is the application of the coil and how does it work?**

Ans. It is used in *low-tension* or ***make****-and-****break*** *ignition.*

In an ignition hookup, *the spark occurs at the instant of breaking*

*the circuit, not at the instant of making*, because when the current is flowing it cannot be stopped instantly on account of self-induction, that is, it acts as though it possessed weight.

## SECONDARY INDUCTION COILS

This type of coil consists of *a long iron wire core upon which is wound a* ***primary*** *and a* ***secondary*** *winding.* Its operation is due to ***mutual*** *induction.* See Fig. 15-10.

**Ques. What is mutual induction?**

Ans. That particular case of electromagnetic induction in which *the magnetic field producing an electric pressure in a circuit is due to the current in a neighboring circuit.*

The circuit to which the current is applied is called the *primary circuit* and the circuit is which a current is induced, the *secondary circuit.* In the actual coil, the primary and secondary circuits are made up of *heavy* and *fine* insulated wire, respectively.

**Ques. What is the property of a secondary coil that makes it of great value for most purposes?**

Ans. That property of mutual induction by which *the voltage of the induced current may be* ***increased*** *or* ***diminished*** *to any extent*

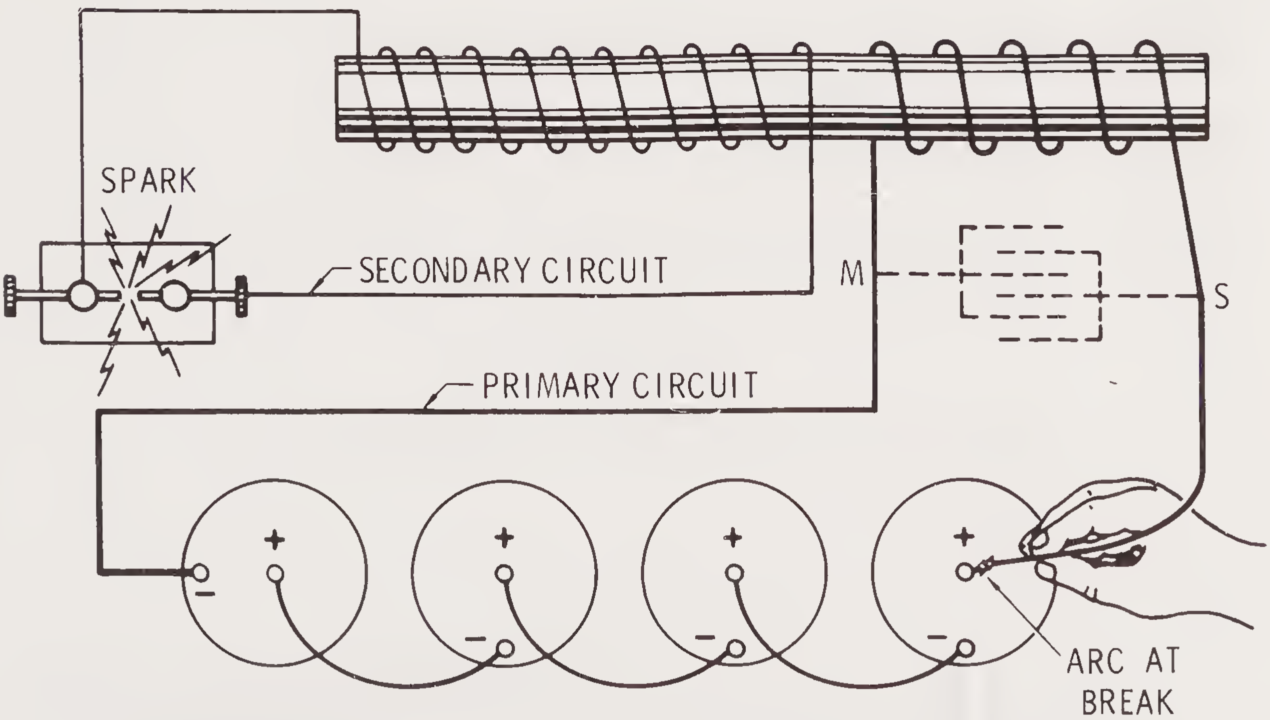



**Fig. 15-10. Production of spark with secondary coil. When the contact is broken at *R*, there will be a pronounced spark across the gap in the secondary circuit.**

*depending upon the relation between the number of turns in the primary and secondary winding.*

**Ques. What is the rule?**

Ans. *The voltage of the induced current is (approximately) to the voltage of the primary current as the number of turns of the secondary winding is to the number of turns of the primary winding.*

This makes it possible to get the *enormous* voltage of the induced current required for high-tension or jump-spark ignition.

## CONDENSER

A condenser, properly named a capacitor, is made up of layers of conductive material separated by a very thin insulator (Figs. 15-11, 15-12, and 15-13). It has the ability to store an electrical charge. The larger the condenser, the more charge it can hold and the longer it takes to fill. The size of the condenser is measured in microfarads.

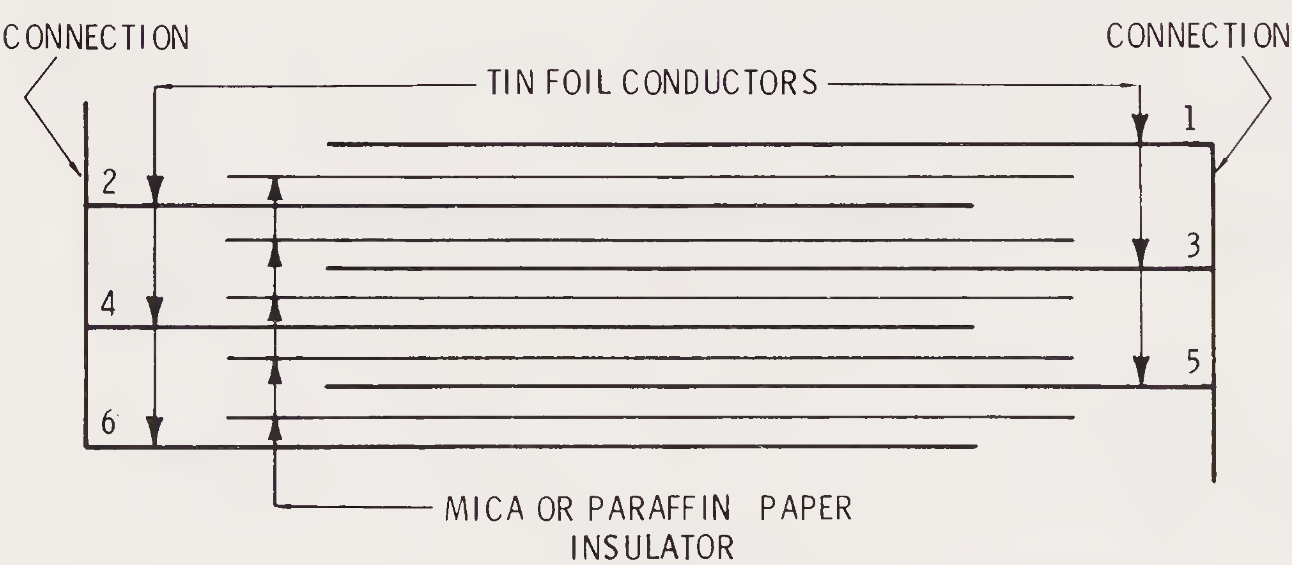



**Fig. 15-11. Construction of condenser.**

**Fig. 15-12. Conventional symbol for a condenser (capacitor).**

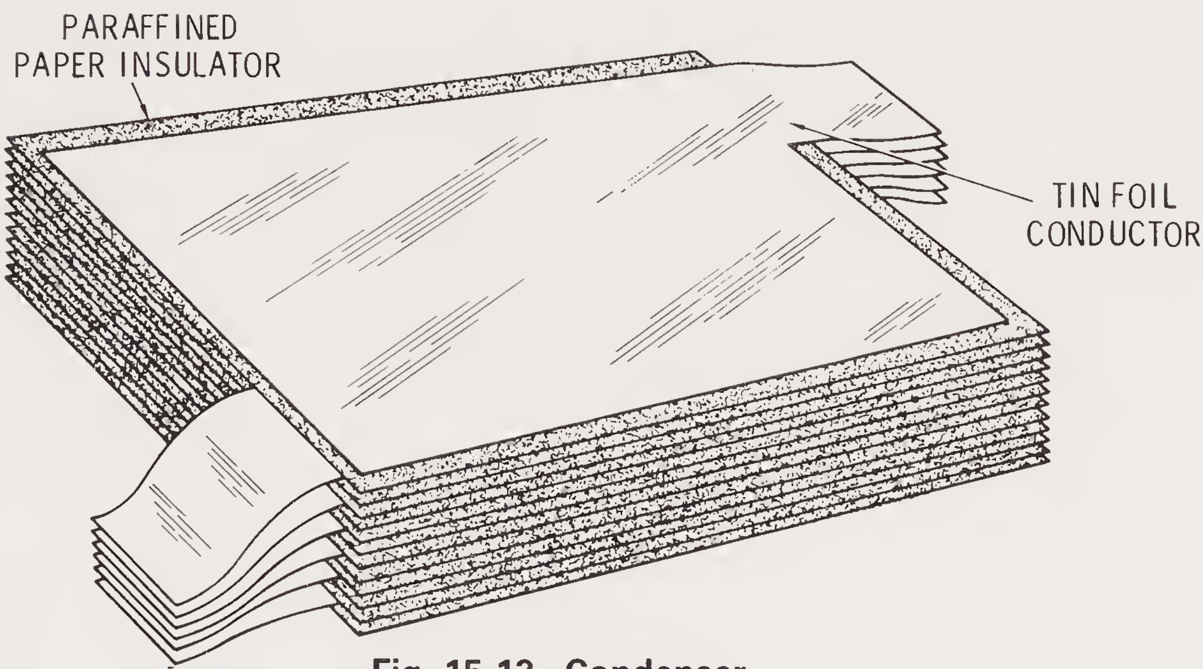



Fig. 15-13. Condenser.

**Ques. What is necessary besides the secondary coil in a jump-spark ignition system to make it work and why?**

Ans. A condenser is used to absorb the induced current of the primary winding and thus prevent it from opposing the rapid fall of the primary current.

## CHAPTER 16

# Ignition Systems

The function of an ignition system is to produce the sparks that ignite the combustible mixture, and to do this so that each engine cylinder will be "fired" in correct sequence. There are two general types of ignition systems: a *battery system* and a *magneto system.*

Battery ignition is used exclusively for motor-vehicle engines; magneto ignition is generally preferred for industrial and small gasoline engines (as for lawn mowers, etc.). Each type of system produces a very high-voltage (15,000 or more volts) current capable of jumping the gap between the two electrodes of a spark plug to create a "hot" (large) spark and efficiently ignite the combustible mixture. In a battery system, this high-voltage current is created by "stepping up" (transforming) the low battery voltage. A magneto is designed to produce the required high-voltage current by simultaneously generating and stepping up a lower-voltage current.

Basically, there are two kinds of battery-ignition systems, which we shall refer to as an *electromechanical* system and an *electronic-*

*ignition* system. These will first be discussed separately, to be followed by a discussion of magneto systems.

## ELECTROMECHANICAL BATTERY IGNITION

This type of system contains two separate electrical circuits known as the *primary circuit* and the *secondary circuit*. The primary is the low-voltage circuit with the battery as its source; the secondary is the high-voltage circuit with an *ignition coil* (a type of transformer) as its source.

Either a 6-volt battery or a 12-volt battery may be used. Most modern automotive engines use a 12-volt battery because 12 volts produce twice the power for engine starting, vehicle lighting, etc., that is produced by 6 volts *with the same amperes of current flow.*

The component parts of a 6-volt primary (low-voltage) circuit (Fig. 16-1) are the battery, an ammeter (when used), the ignition switch, the primary winding of the ignition coil, and the cam and breaker points of the distributor. A 12-volt primary circuit is the same except that a coil resistor is added into the circuit between the coil and the breaker points.

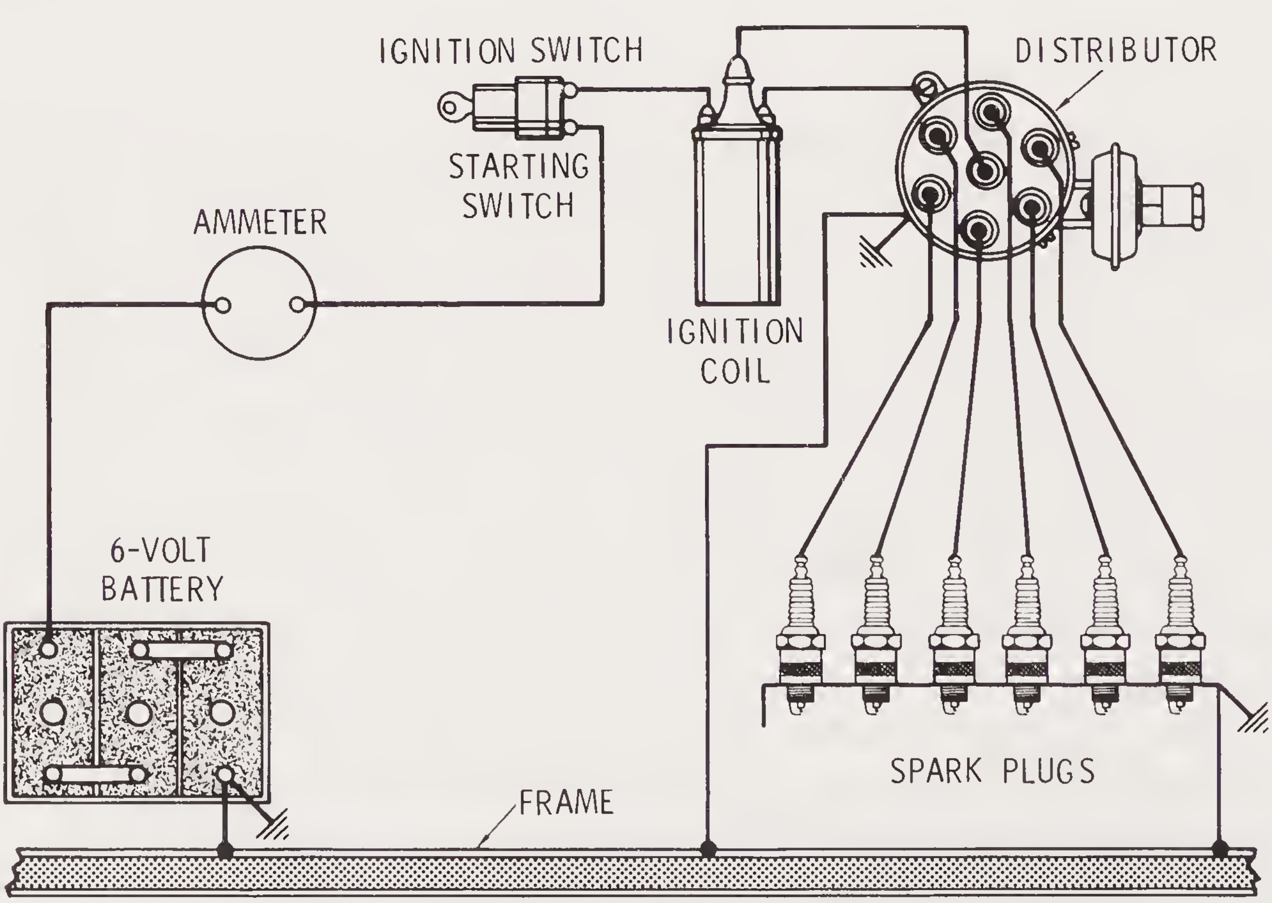



**Fig. 16-1. Wiring diagram of a typical six-cylinder battery ignition system.**

In either case, the secondary (high-voltage) circuit is composed of the secondary winding of the ignition coil, the cap and rotor of the distributor, the spark-plug leads, and the spark plugs.

In any battery-ignition circuit, the battery serves as the source of electrical energy only until the engine is running; afterwards, the generator (or alternator) takes over.

## Ammeter

An ammeter, although not essential to the operation of the primary circuit, is sometimes used to indicate the condition of the battery and proper functioning of the battery-charging circuit (between the battery and the generator or alternator). In many automotive applications a dashboard light, which flashes on at an appropriate time, replaces the ammeter to indicate that the charging circuit is inoperative.

## Ignition Switch

Fundamentally, the ignition switch is simply a manual switch used to open or close the primary circuit. In most automotive applications, however, it is a much more complicated device that serves, in one position, to energize the engine-starting and ignition-primary circuits; then, in a second position (to which it is returned by a spring), to energize the ignition-primary circuit and all other vehicle circuits except the starting circuit. There also may be a third position (manually selected) in which this switch energizes only selected vehicle circuits (such as for the lights radio, etc.).

**Note:** Because an engine starter draws a considerable amount of current (amperes), which tends to burn up ordinary switch contacts, the starter circuit generally is not energized through the ignition switch. Instead, this switch, when in starting position, energizes a *starter solenoid* (switch) that, when energized, closes heavy-duty (high-amperage) contacts through which the starter current is passed. See Fig. 16-2.

## Ignition Coil

The primary winding of an ignition coil is made up of a few hundred turns of relatively large-diameter wire (to carry the low-voltage,

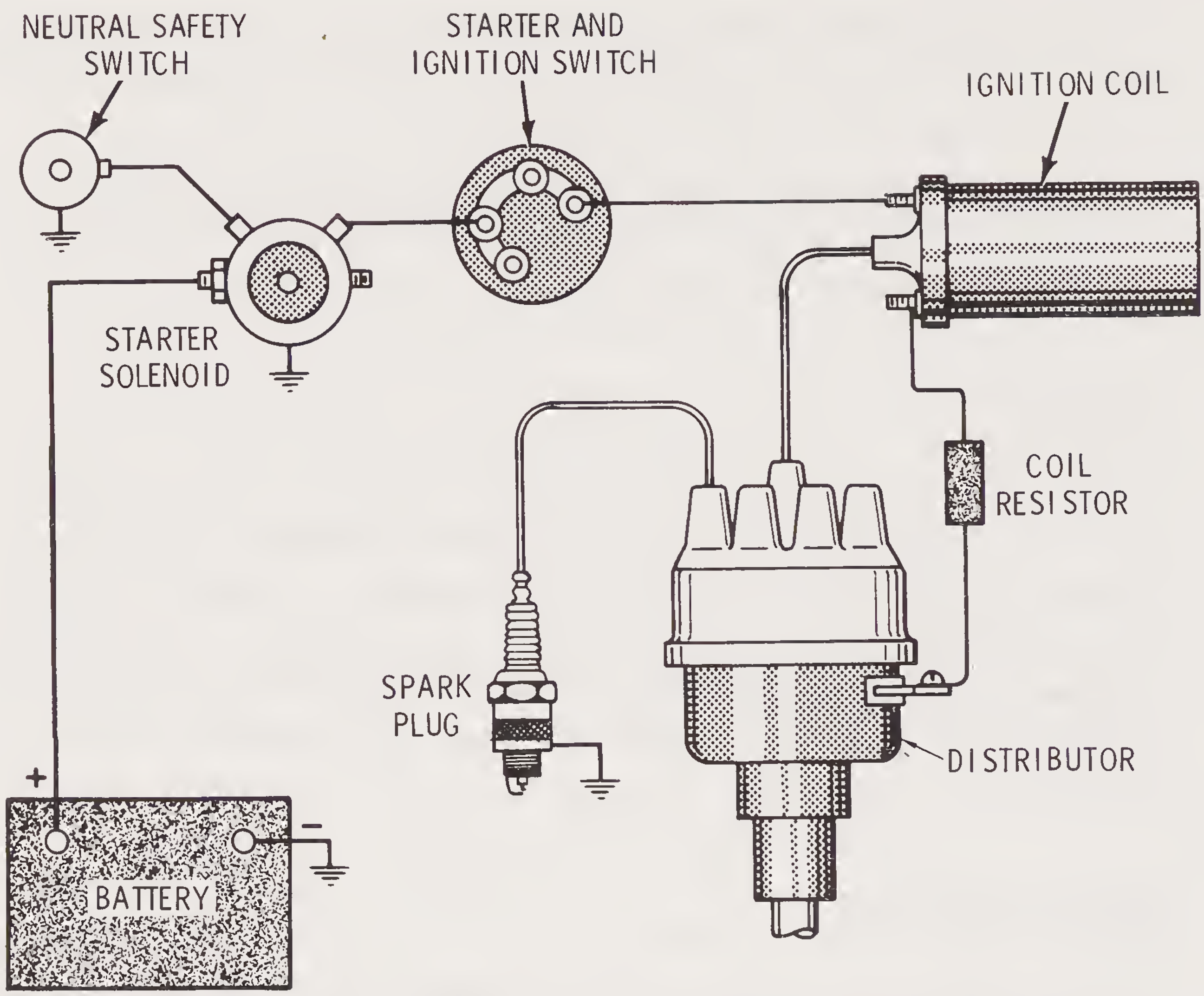



**Fig. 16-2. Wiring for a 12-volt system with coil resistor and starter solenoid.**

high-amperage current of the battery—or generator or alternator—circuit). The secondary winding consists of several thousand turns of relatively small-diameter wire (capable of carrying the high-voltage but low-amperage secondary-circuit current). The primary winding is on the outside, the secondary winding is inside, and at the center there is a coil core made up of thin layers of soft iron laminations (which serve to increase the coil efficiency). This assembly is surrounded by a layer of insulating compound, then a shell of soft iron (which further increases the coil efficiency by completing the magnetic circuit). Around this entire assembly there is a protective housing filled with insulating compound, usually oil or epoxy.

When the primary circuit is closed, the flow of current through the coil's primary winding builds up a magnetic field; when the primary circuit is opened, the instantaneous break of current flow causes this magnetic field to suddenly collapse. Hence, as the distributor breaker points continuously close and open the primary circuit, the magnetic field continuously builds up and collapses.

This magnetic activity induces a corresponding current in the coil's secondary circuit; but, because of the difference between the number of turns of wire in the primary and secondary, the current in the secondary is of much greater voltage (more force with which to "jump" the spark plug's gaps).

## Ignition Resistors

Ignition coils generally are designed to operate on less than 12 volts. Therefore, in a 12-volt engine system it is necessary to reduce the primary voltage from 12 volts. This is done by using a resistor (which "consumes" the excess voltage). In addition to protecting the coil from too high a voltage, the resistor also protects the distributor breaker points (which, also, are intended for less than 12 volts).

A resistor is simply a predetermined amount of resistance (to current flow) which, by resisting the current flow, lowers its force (voltage) by converting part of the force into heat. Some materials conduct electricity with very little resistance (heat loss); others will conduct electricity, but do it so poorly that the heat loss (and consequent reduction of voltage) is considerable. There are two types of "poor" conductors used to reduce the voltage from 12 volts.

1. *Block-type ballast resistor.* This is a compact unit consisting of a high-resistance material in a housing, which is connected in series with the primary circuit. The material used has a much higher resistance after it is heated (by the passage of current through it, which creates the heat) than when it is cold. Therefore, in the beginning (when it is cold) it allows almost the full voltage of the system to energize the coil's primary winding to assist starting; but as current flows and it heats up, it reduces primary-circuit current to the desired operating voltage.
2. *Wire-type resistor.* Resistance is provided simply by a special-material high-resistance wire.

## Spark Action

When the primary contacts (cam and breaker points) in the distributor are closed, current flows from the battery through the primary

winding and points to ground. This flow of current produces a magnetic field, which collapses very rapidly when the circuit is opened. This collapsing of the field intersects the coil windings and induces the necessary high voltage in the secondary winding of the ignition coil. The high voltage surge is great enough to overcome the resistance of the spark plug gap, and to produce a spark that ignites the fuel mixture. The induced voltage will vary depending on the design of the coil and secondary ignition system.

## Distributor

The distributor is essentially a switching device consisting of a combination of switches working in unison with each other; one makes and breaks the primary circuit, and the other makes and breaks the secondary circuit while distributing secondary current to the spark plugs in correct firing order. There are two basic types of distributors: the *conventional* (electromechanical) type, and the more recently developed *electronic* type (referred to as an *electronic ignition system*).

The cam and breaker points (Fig. 16-3) serve to interrupt the primary circuit at certain definite intervals. The cam is located on the distributor shaft, which is driven indirectly by the engine crankshaft.

Ordinarily, the cam will have as many lobes as an engine has cylinders and is rotated half as fast as the crankshaft. As the distributor shaft rotates, the cam opens the breaker points and interrupts the primary circuit. Within the time necessary for one revolution of the cam, the four-stroke cycle has been completed within each cylinder and the primary circuit has been interrupted once for each cylinder. Thus, the cam and breaker points located in the distributor actually comprise a precisely set timing device operating in exact synchronicity with the engine.

The second function of the distributor is to conduct the high-voltage surges from the secondary winding of the ignition coil to the proper spark plug at the correct time. This is performed by the distributor cap and rotor. As will be noted in the circuit diagram (Fig. 16-1), the circuit continues through the center of the cap to the rotor, which is a revolving arm. As it rotates, the outside edge of the arm lines up with the electrodes connected up through the

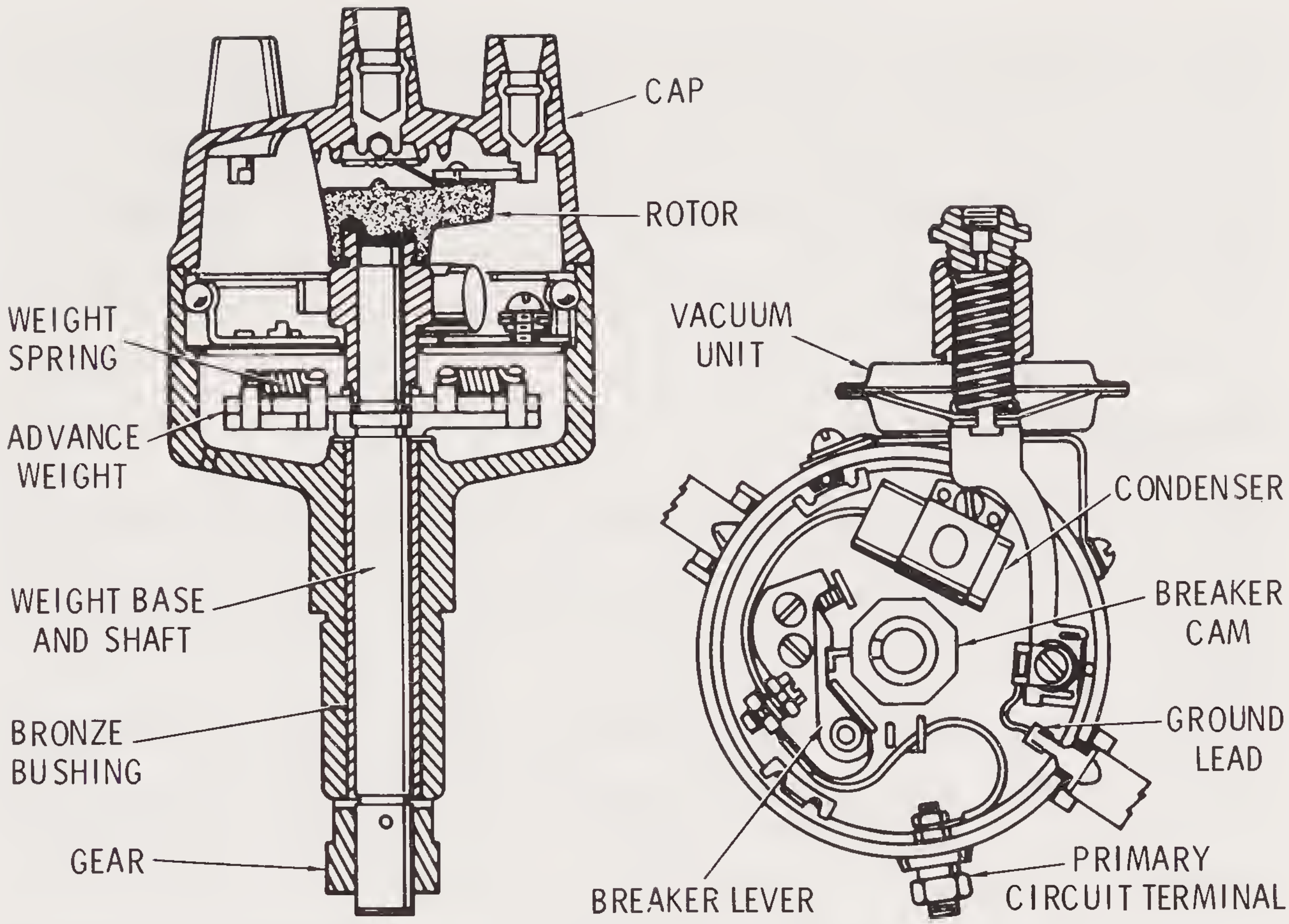



**Fig. 16-3. Details of a typical distributor.**

cap to the terminals in which the spark plug leads are inserted. These terminals are located near the outside edge of the cap.

Since the rotor must line up with the lead to a spark plug each time the high-voltage surge is produced, and since a surge occurs each time the cam interrupts the primary circuit, the distributor cam and the rotor must be driven by the distributor shaft to synchronize their operation.

Timing is accomplished by adjusting the position of the distributor so that the breaker points open and the rotor is aligned with the spark plug lead at the proper moment for igniting the fuel mixture in the cylinder.

The leads to the spark plugs must be well insulated to withstand the high voltage to which they are subjected. One end of the leads is inserted into the terminals of the distributor cap and the other end is connected to the spark plug.

## Spark Plugs

The spark plug serves to produce the spark necessary to ignite the compressed charge of air and fuel in the engine cylinder. Ignition

occurs at the gap of the plug across which high voltage from the ignition coil jumps in the form of a spark. The second electrode of the spark plug is attached to the steel-shell part of the plug and is grounded to the frame through the engine block assembly. See Fig. 16-4.

## Condensers

The condenser as employed in battery ignition systems has a double duty in that it (1) prevents arcing at the primary contacts and (2) speeds up the collapse of the magnetic field by reversing the primary voltage surge.

The collapse of the magnetic field, which induces a high voltage in the secondary circuit, simultaneously induces a fairly high voltage in the primary circuit. This voltage would produce a strong spark across the small gap established as the breaker points open to interrupt the circuit. Without the condenser action, the contacts

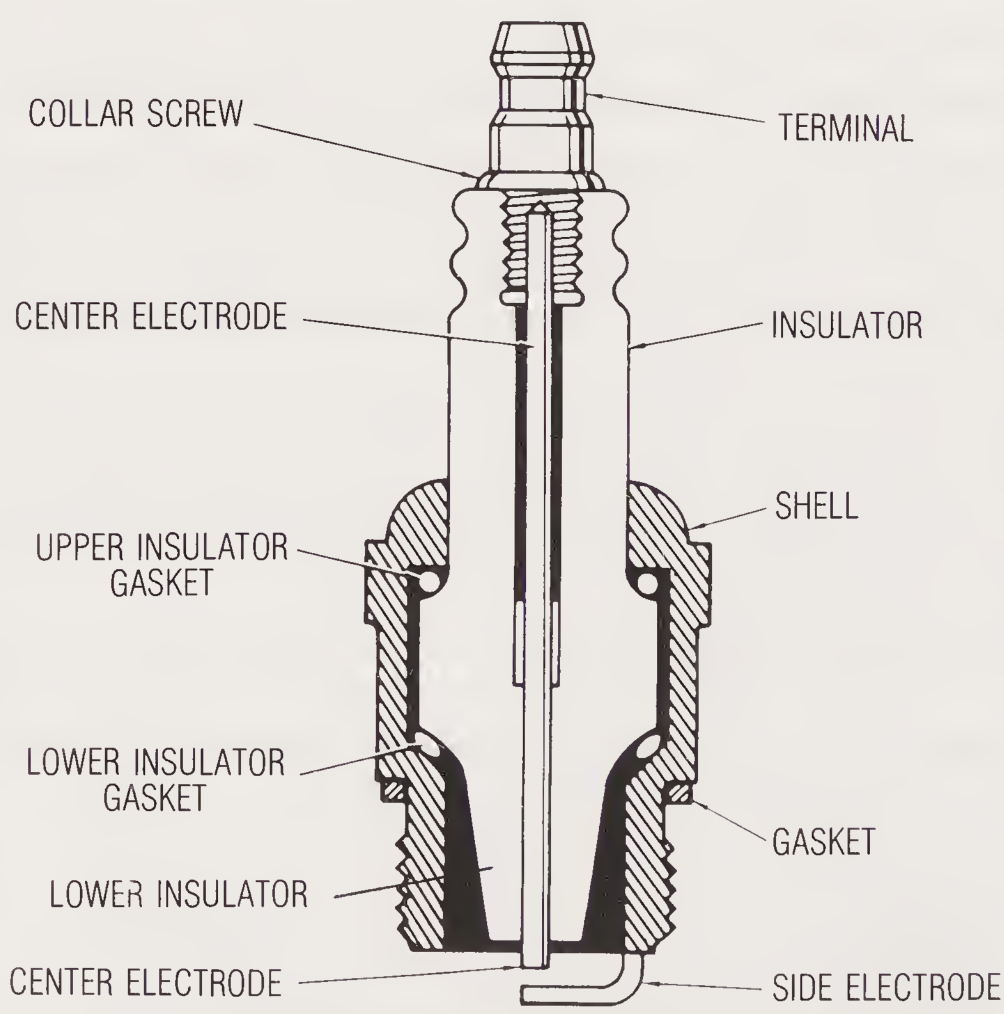



**Fig. 16-4. Cross section of typical spark plug.**

would be severely burned, and most of the energy stored in the coil would be lost.

With the condenser connected across the primary contacts, an additional path is established for the current flow during the first instant the contacts begin to separate. The current thus flows into the condenser instead of arcing across the contact points. This action stops the flow of primary current, charges the condenser, and hastens the collapse of the magnetic field. Very soon after the high-tension spark appears at the spark plug electrode, the current stored in the condenser discharges back through the primary circuit. This process is repeated for every power stroke of the engine.

The capacity of a condenser is measured in microfarads ($\mu F$) and is determined by the area of the foil and the thickness of the insulating sheets. Ignition condensers are usually manufactured in the range of from 0.15 to 0.30 $\mu F$. See Fig. 16-5.

## Spark Control

In order to obtain efficient operation of an internal combustion engine throughout the speed range under various operating conditions, it is essential that the spark occur at the correct instant. This exact instant will vary according to engine load and speed. Various mechanisms have been provided to provide automatically the advance or retard of the spark as load and speed conditions

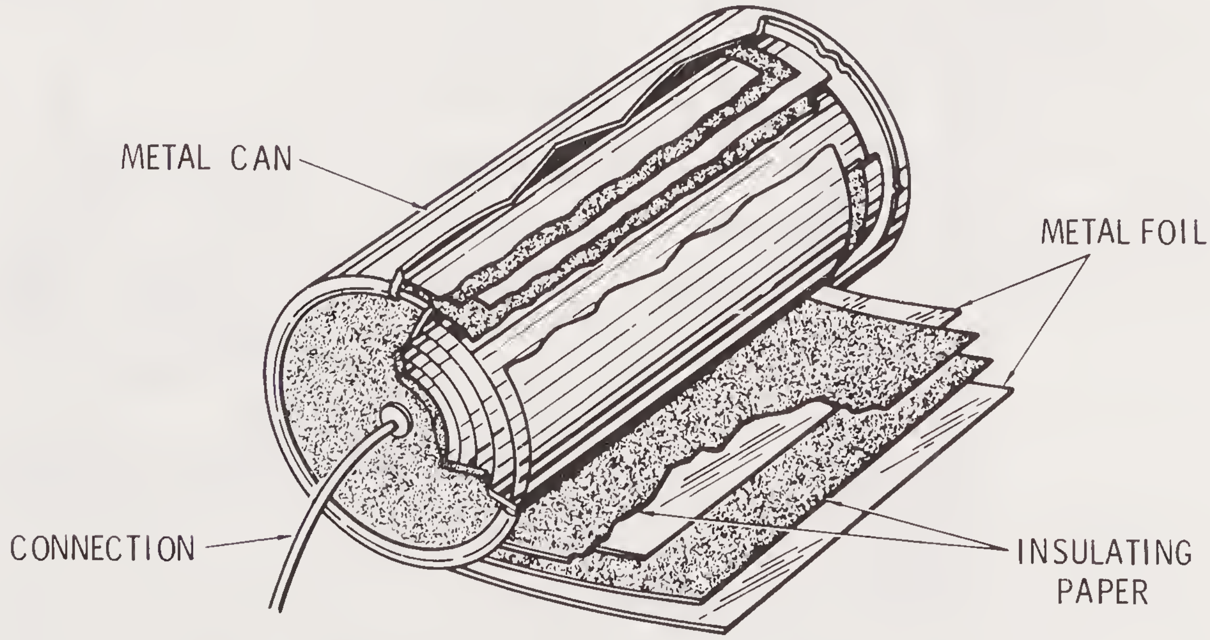



**Fig. 16-5. Details of typical ignition condenser.**

require. The two most common methods employed for spark control are:

1. The centrifugal force method.
2. The engine vacuum method.

On motor vehicles spark control may be obtained by either method, or by a combination of both.

## Centrifugal Force Method

The centrifugal force method of spark control, as shown in Figs. 16-6 and 16-7, consists essentially of a centrifugal governor having two weights that swing out against spring tension as the engine speed increases. The centrifugal governor is mounted on the distributor shaft, beneath the breaker plate in the distributor, and is linked

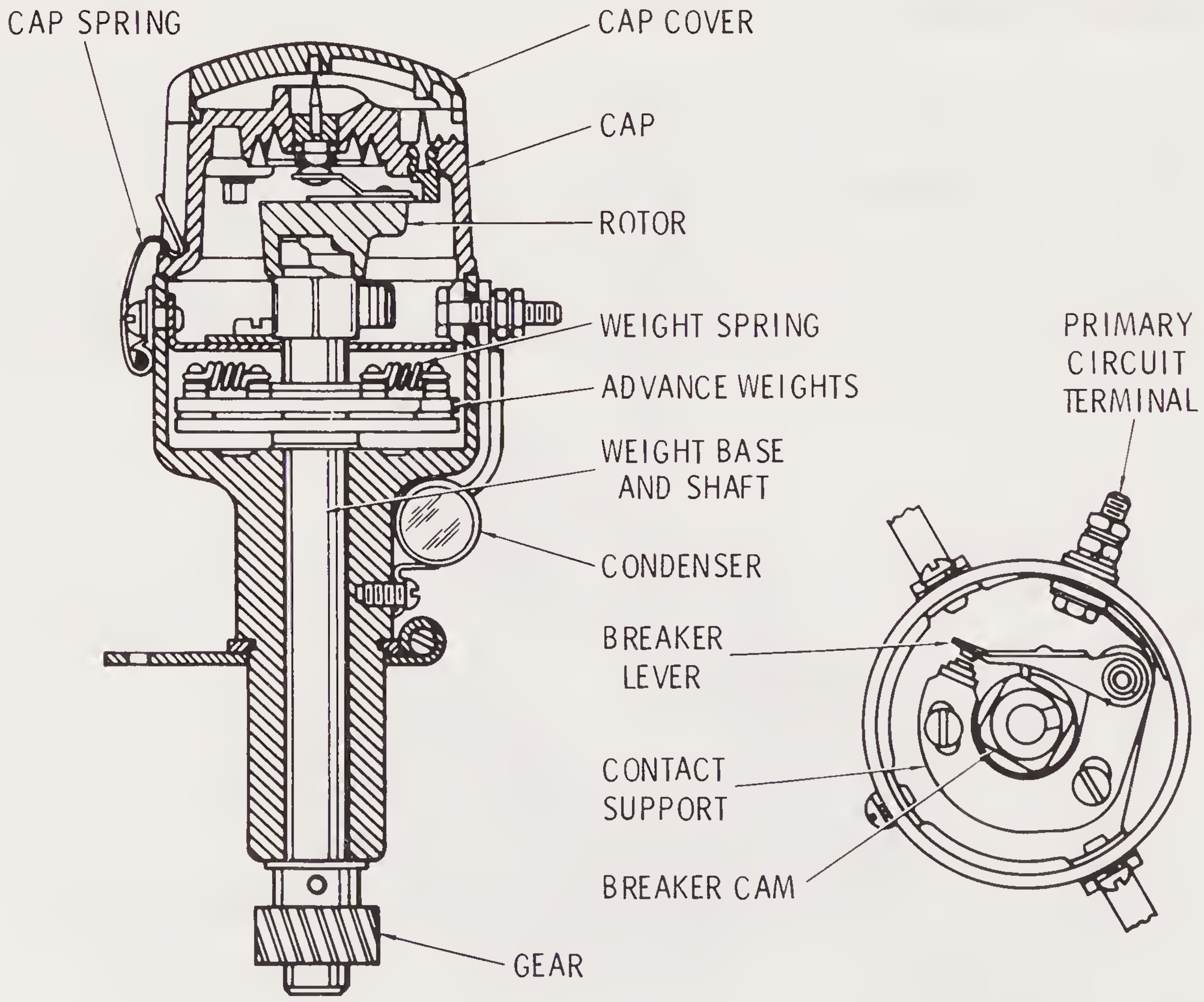



**Fig. 16-6. Automatic spark-advance type of distributor.**

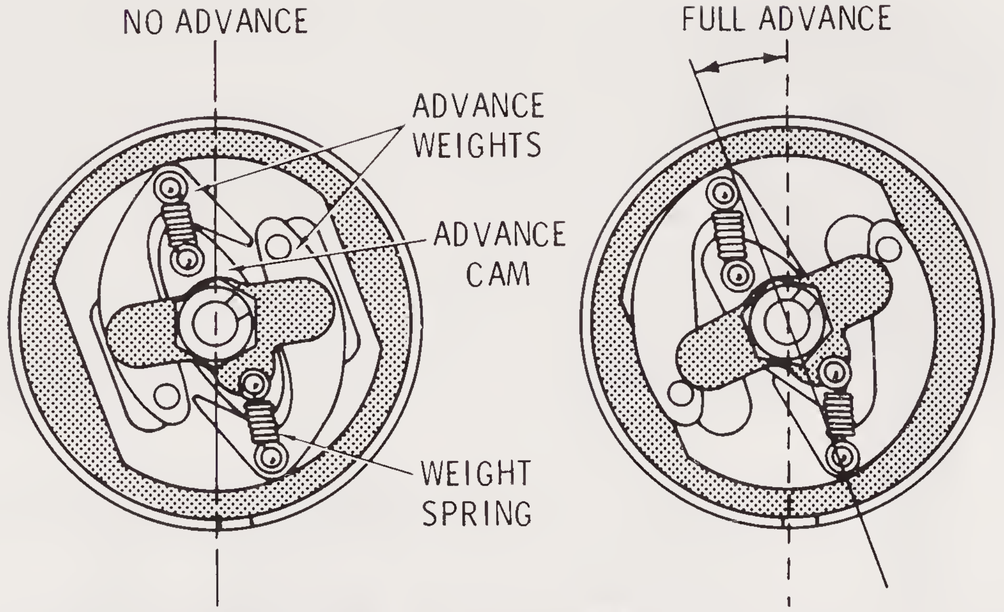



**Fig. 16-7. Typical mechanical spark-advance mechanism.**

through the shaft to the cam, which is mounted above the breaker plate and operates the breaker points.

As the engine speed increases, the advance weights of the governor fly outward due to the centrifugal force, against action of the weight springs, and cause the distributor cam to shift forward in relation to the distributor shaft. The shifting of the cam will make the breaker points open earlier and thus advance the spark automatically to the correct position in relation to the engine speeds.

As the speed decreases, the weights gradually return to their slow-speed position by the springs. This shifts the cam in the opposite direction, thus making the points open later and retarding the spark. The centrifugal governor reacts only to engine speed.

When the throttle is only partly open, the engine cylinders take in only part of the full charge during each intake stroke, resulting in low compression pressures and slow burning of the charge. For improved performance and full economy during such operation, intake manifold vacuum is used to obtain greater spark advance than is possible with the centrifugal governor alone.

## Engine Vacuum Method

In the engine vacuum method of spark control, also termed the *vacuum advance spark control*, a vacuum diaphragm is usually mounted on the distributor housing and linked to the breaker plate (Fig. 16-8). A vacuum chamber next to the diaphragm is connected

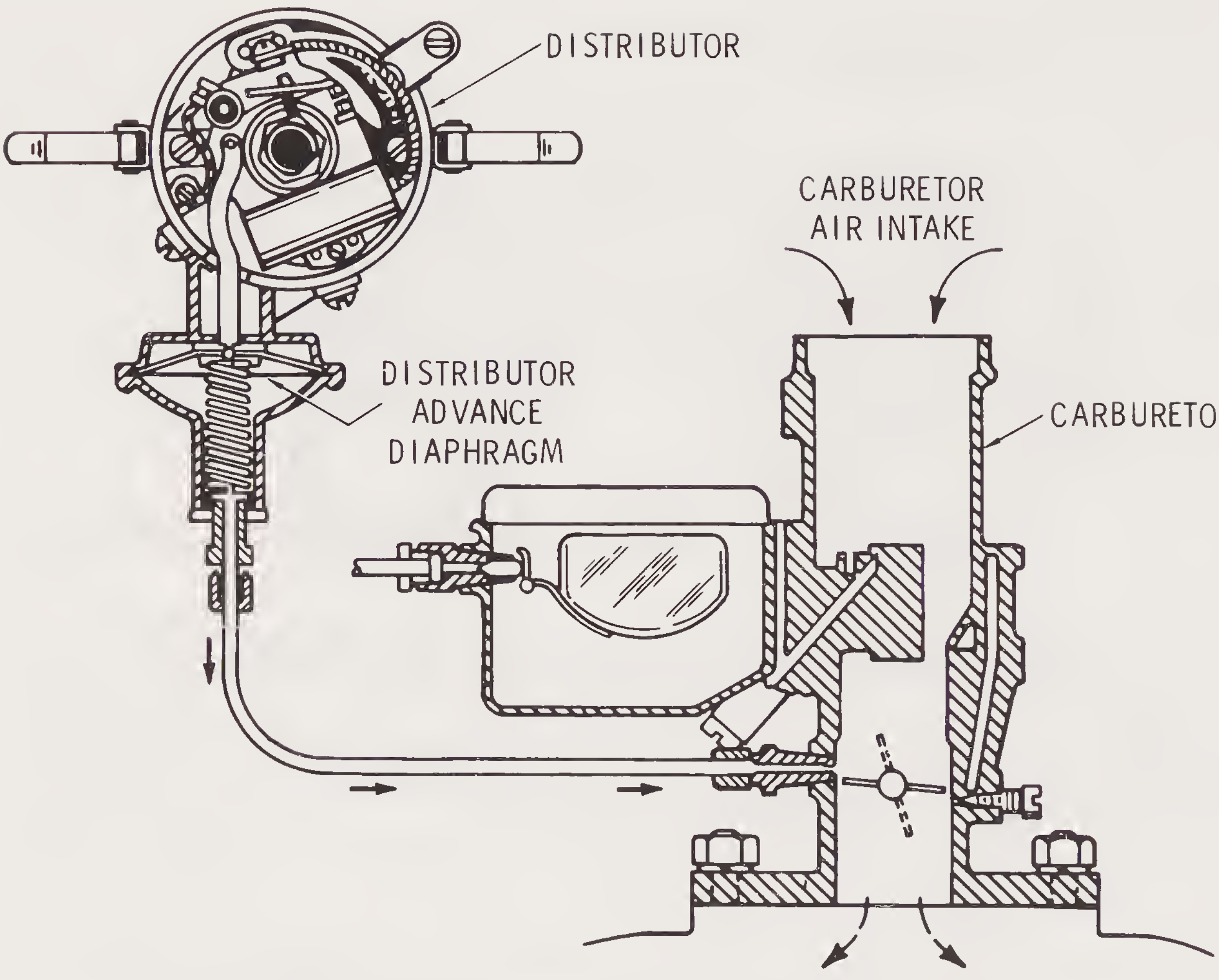



**Fig. 16-8. Vacuum advance spark control mechanism.**

to the intake manifold so that changes in the manifold vacuum will operate the diaphragm.

When the engine is not running, the breaker plate is in the retard position with the diaphragm held in the normal position by the diaphragm spring. A vacuum created in the intake manifold actuates the diaphragm against the spring, shifting the breaker plate to an advanced position, thereby giving more spark advance than that obtained with the centrifugal governor alone. On quick acceleration or open throttle condition, the vacuum in the manifold decreases, allowing the compressed diaphragm spring to return the breaker plate to the retard position.

In another method of vacuum advance, intake manifold vacuum is utilized to actuate a piston brake against the advance plate of the governor. In this method, a high vacuum draws the piston brake away from the advance plate, compressing the spring and permitting the governor to control the spark advance.

If the engine is suddenly accelerated or operated under heavy

load, the intake manifold vacuum decreases, allowing the compressed spring to actuate the brake against the advance plate. The friction imposed by the brake upon the advance plate exerts a force counter to the centrifugal force of the weights so that the weights move inward, retarding the cam. As soon as the intake manifold vacuum increases, the piston brake is pulled back, permitting the weights to fly outward and advance the timing. This system is seldom used but does facilitate easier starting.

### Electronic Spark Control

Many modern automotive engine designs utilize electronic spark control. The distributors used with these engines have no means of controlling spark timing. The complete control of spark timing is accomplished through a computer system similar to the type used with electronic fuel injection. A system of sensors, as used with EFI, signals the computer of the engine's operating conditions and the computer electronically adjusts the spark timing.

## ELECTRONIC BATTERY IGNITION

The essential difference between this system and an electromechanical system is the elimination of the (mechanically operated) breaker points and cam. Breaker-point pitting and cam wear are dispensed with, thus making it less necessary to service the distributor. In some systems a conventional ignition coil (discussed previously) is used; in other systems a different, but separate, ignition coil is used; and in still other systems, the ignition coil is an integral part of the distributor assembly.

In addition, there are several types of electronic ignition systems, some requiring a (separate) control unit (Fig. 16-9), or amplifier. Each system also incorporates an ignition switch, either an ammeter or a dashboard light, a starter and a starter solenoid, as previously discussed.

A conventional ignition coil is used, and the distributor is conventional except that a stationary *sensor* (also termed *stator* or *pickup*) and rotating *trigger wheel* (also termed *rotor, armature* or *reluctor*) replace the cam, breaker points and condensor. See Fig. 16-10. There is a solid-state, modular, electronic *control unit* con-

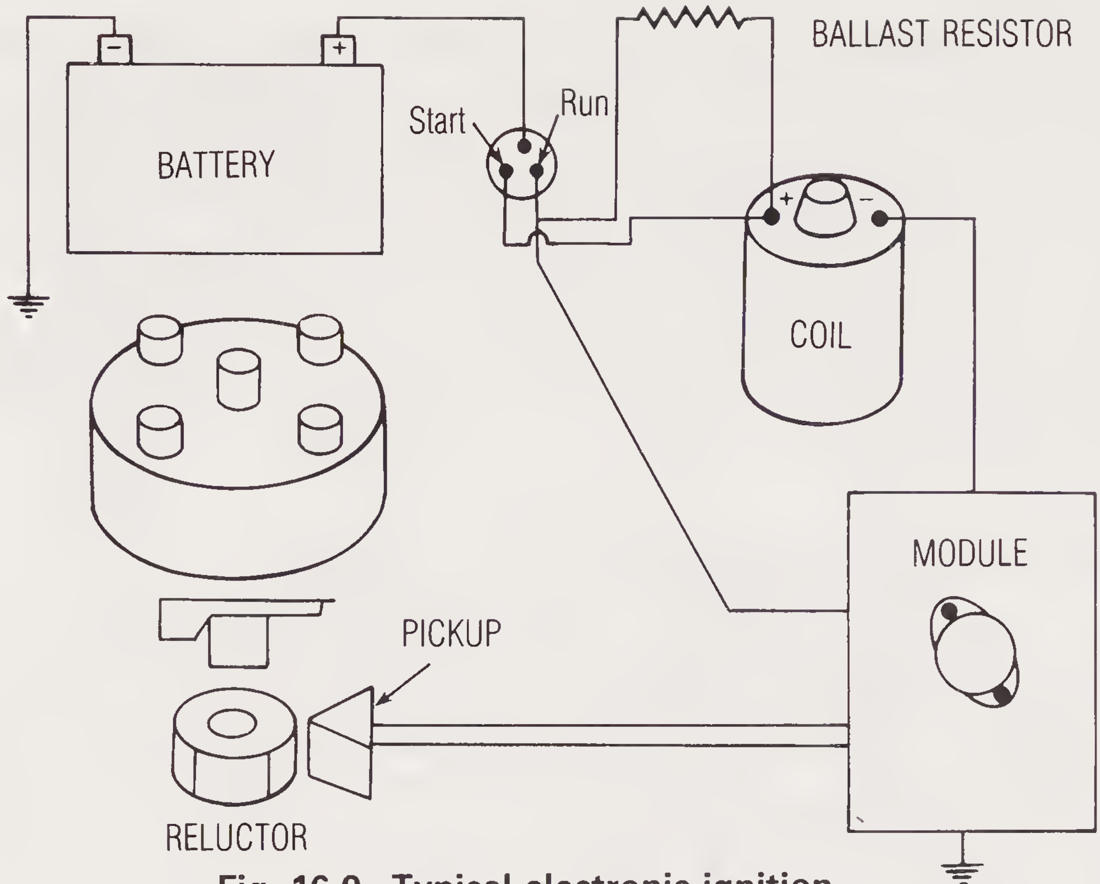



**Fig. 16-9. Typical electronic ignition.**

nected into the circuits between the distributor and coil primary. This unit contains a current regulator and a power transistor which control battery current in the coil's primary winding. It may also contain an oscillator that furnishes current to excite the sensor, which in turn develops an electromagnetic field through which the trigger wheel rotates. Each time one of the trigger wheel teeth enters this field, the oscillator acts on the transistor, causing it momentarily to cut off current flow through the ignition coil primary, thus creating the high-voltage secondary-circuit current as previously described.

In similar systems, the sensor is called a *pickup coil assembly* and the trigger wheel is called a *reluctor*. Also, in place of a current regulator in the control unit a (separate) *ballast resistor* may be connected so as to control voltage to the primary coils after the ignition switch is turned (from start) to the on position. In such a system a permanent magnet in the pickup is used to produce a magnetic field that is interrupted by the reluctor (Fig. 16-9).

## Capacitor-Discharge (CD) System

This system has a *magnetic-impulse distributor*, an *amplifier unit*, a *high-capacity condenser* and a standard ignition coil. The second-

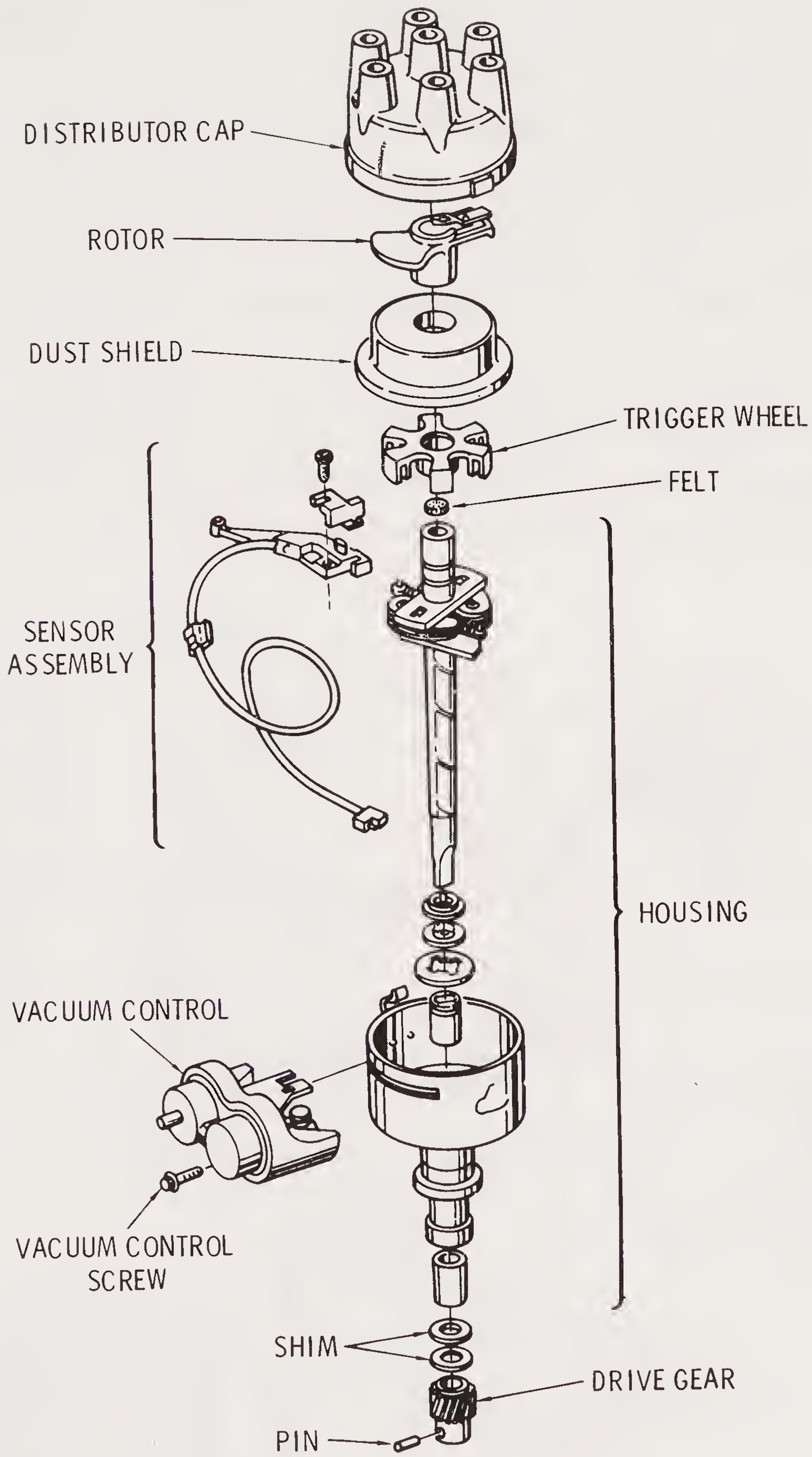



**Fig. 16-10. A typical breakerless distributor.**

ary (high-voltage) circuit is conventional (distributor has a cap and rotor), but the primary circuit is electronically timed. This is accomplished by a *timer core* and a *magnetic pickup assembly* in the distributor. See Fig. 16-11.

Battery voltage is applied to the high-capacity condenser (rather than to the ignition-coil primary), which builds up a high (300 volt) charge in the intervals between discharge. The iron timer core of the distributor has projections, one for each cylinder, and the pickup assembly consists of a permanent magnet, a coil and a pole piece with internal "teeth" to match the timer-core projections. At the proper intervals, the projections line up with the teeth to establish a magnetic path through the coil, which is energized through the system amplifier and thereupon permits a current to flow through a circuit in the amplifier. The voltage of this current is amplified

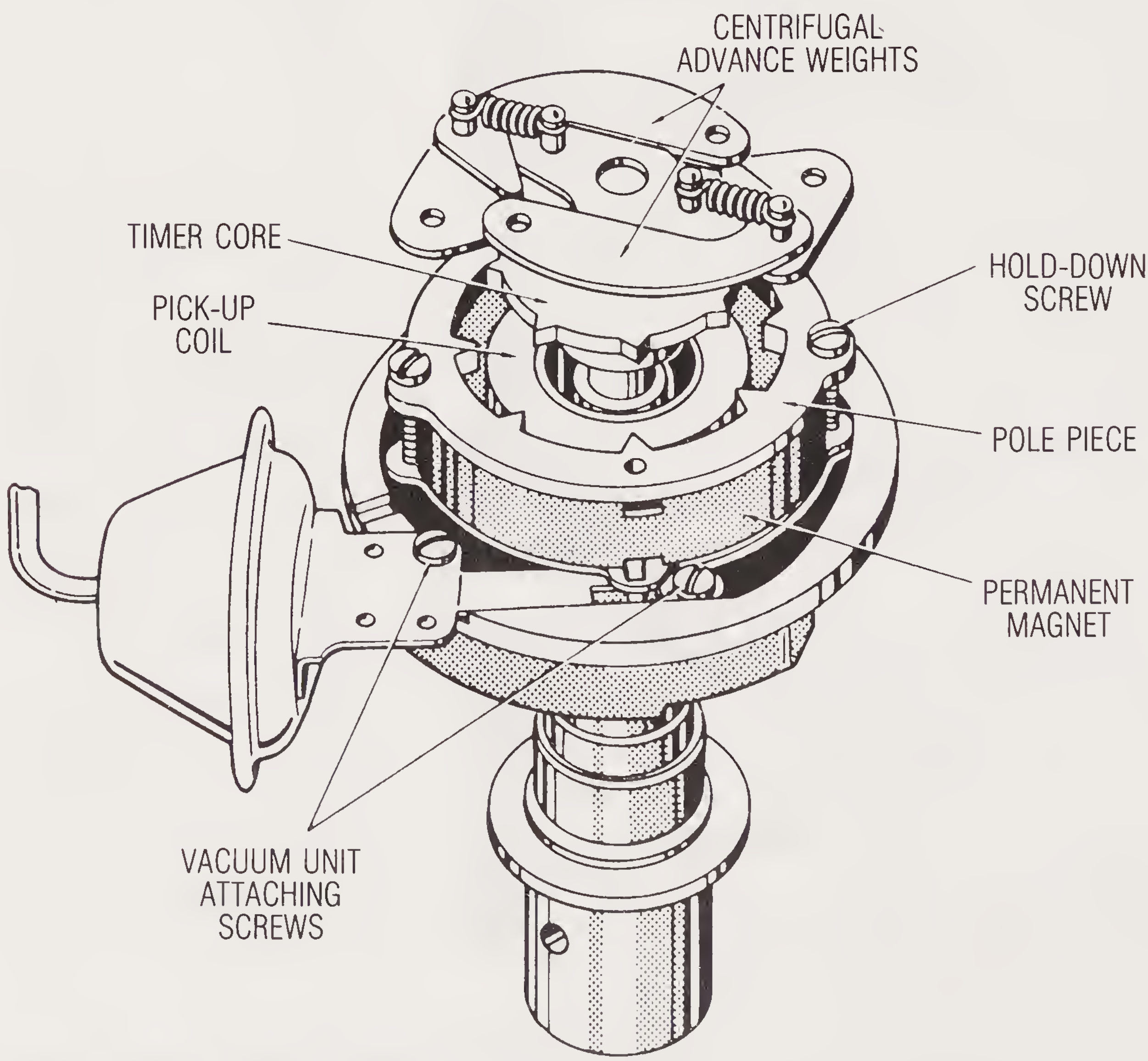



**Fig. 16-11. Components of a magnetic-impulse distributor.**

to activate a thyristor (in the amplifier), which then "turns on" the primary circuit.

"Turning on" the primary circuit allows the high-capacity condenser to discharge through the amplifier and the ignition-coil primary, thus creating a momentary current that, in turn, is transformed by the coil into the required very-high-voltage secondary current. In short, this system creates the secondary current by momentarily sending a relatively high-voltage current through the primary, rather than by momentarily interrupting primary current. See Fig. 16-12.

Variations of these electronic ignition systems (referred to as *unit ignition* and *high-energy* systems) differ principally in the elimination of the standard ignition coil. Instead, a coil is incorporated within the distributor assembly. Operation is similar to the fore-

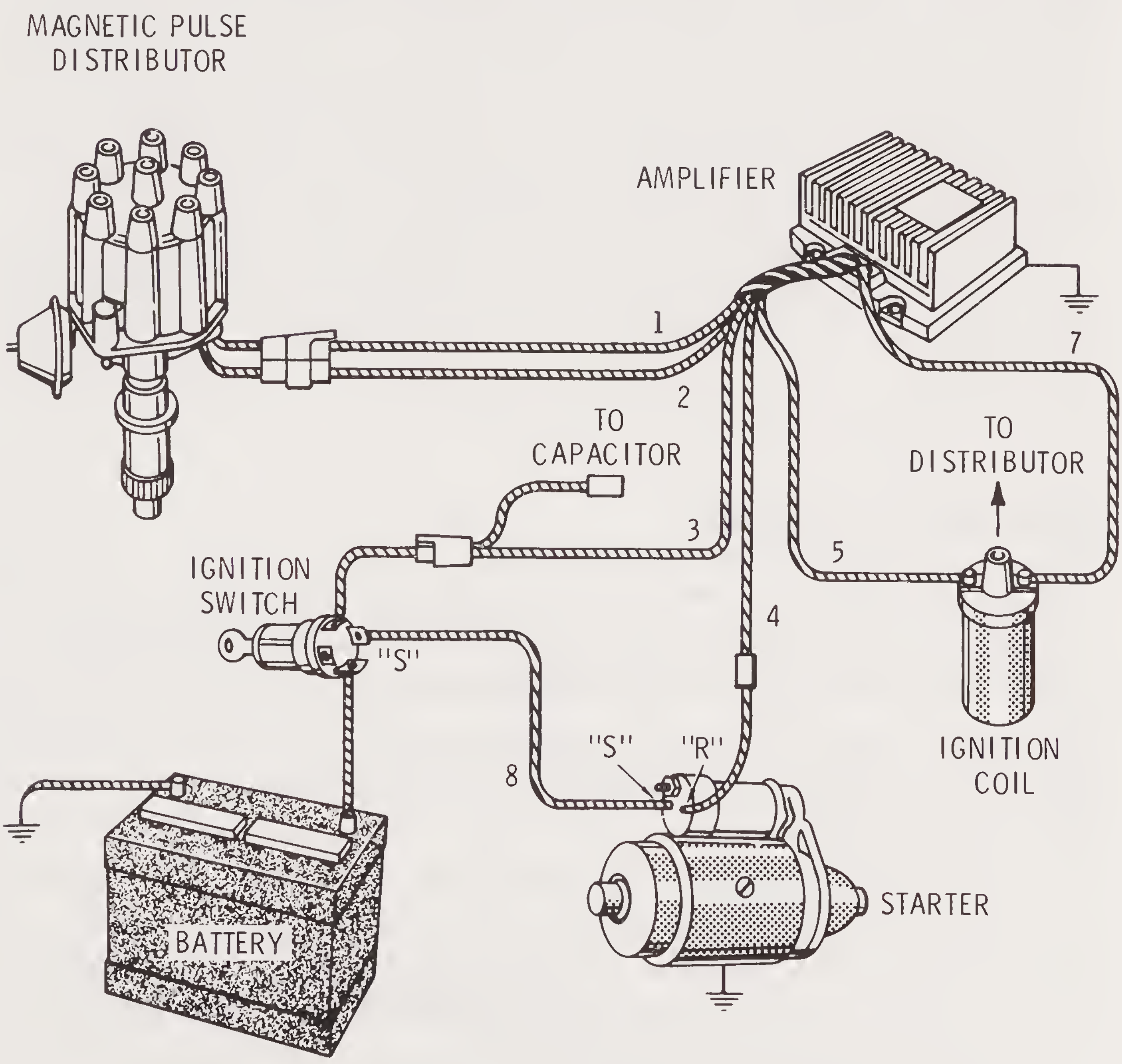



**Fig. 16-12. Typical capacitor-discharge (CD) system.**

going. The differentiating factor is the small, integrated microchip electronic module used in place of the large external-control unit.

### Breakerless Systems

All breakerless systems fall into the category of electronic ignition systems. They may be of any type using externally mounted or integral coils, or be of the capacitive discharge design.

## MAGNETO IGNITION

Magneto ignition, as the name implies, is provided by a magneto, which is a compact combination of a generator, ignition coil and distributor. Magneto ignition is usually provided on internal combustion engines that do not require a lighting system or other current-consuming devices in connection with their operation. In some applications, however, such as on outboard motors, both magneto and battery-operated ignition systems are available.

In ignition systems suitable for magneto use, there are certain advantages over battery ignition in that it is generally more reliable, requires little maintenance and, perhaps most important, does not have a battery to run down or wear out.

### Operation Principles

Electrical energy in magneto ignition is obtained by a generator utilizing the principle of electromagnetic induction to produce electricity. It should be clearly understood that in order to generate electricity, three things are necessary: (1) an electrical conductor, (2) a magnetic field, and (3) relative motion between the field and the conductor.

In the magneto, a permanent magnet supplies the magnetic field, a wire coil serves as conductor and the engine provides mechanical energy for the motion between the field and the conductor. There are two types of magnetos in general use. They are:

1. Magnetos with rotating conductors.
2. Magnetos with rotating magnets.

Both principles, the moving conductor and the moving magnet, have been utilized in providing ignition. However, due to improved magnetic materials, the rotating-magnet principle is now most commonly used.

## Rotating-Conductor Magnetos

Fig. 16-13 illustrates schematically the circuit arrangement of a rotating-conductor magneto. The primary circuit consists of a primary winding on a rotating armature, a condenser and an interrupter. One end of the primary winding is grounded through a grounding brush, while the other end is brought out to the interrupter through a slip ring or contact button.

The interrupter, or breaker mechanism, is shown below the magneto (for clearness), but in reality the interrupter is mounted on an extension of the armature shaft. When the contact points are closed, the primary current passes to ground. The condenser is connected across the contact points. The ground terminal is electrically connected to the insulated contact point. A wire is connected between the ground terminal and the switch. With the switch in the off position, this wire provides a direct path to ground for the primary current.

The secondary circuit consists of a secondary winding on the armature and the distributor. One end of the secondary circuit is grounded to the primary and the other end to the rotor in the distributor, which conveys the secondary current in the proper sequence to the spark plug electrodes of the distributor.

The high-tension current produced in the secondary winding passes to the central insert of the distributor finger by means of a carbon brush. From this point the secondary current is conducted to the high-tension segment of the distributor finger and across a small air gap to the electrodes of the distributor block. See Fig. 16-14.

## Rotating-Magnet Magnetos

Because of improved magnetic materials, the rotating-conductor type is now largely superseded by the more efficient rotating-magnet magneto. In a rotary-conductor magneto, the windings are subjected

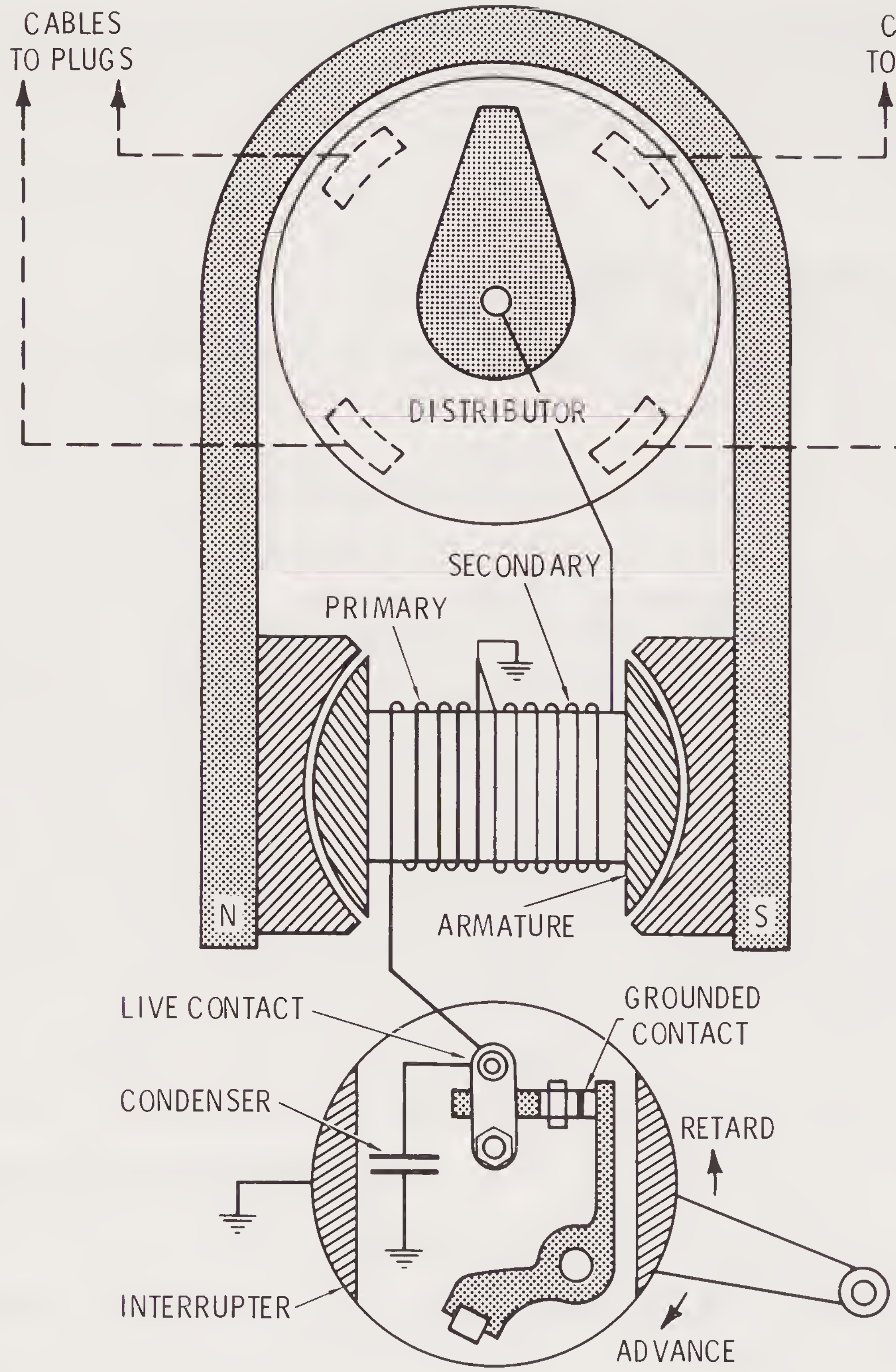



**Fig. 16-13. Rotating-conductor magneto.**

to considerable centrifugal stress due to high rotative speed, resulting in winding failure, the sliding of the collector contacts and added maintenance and repairs.

In the rotating-magnet type, on the other hand, only the solid magnet and pole pieces rotate. The result is a magneto capable of higher speed and more energy for a given size. Fig. 16-15 illustrates schematically the various components of a rotating-magnet magneto.

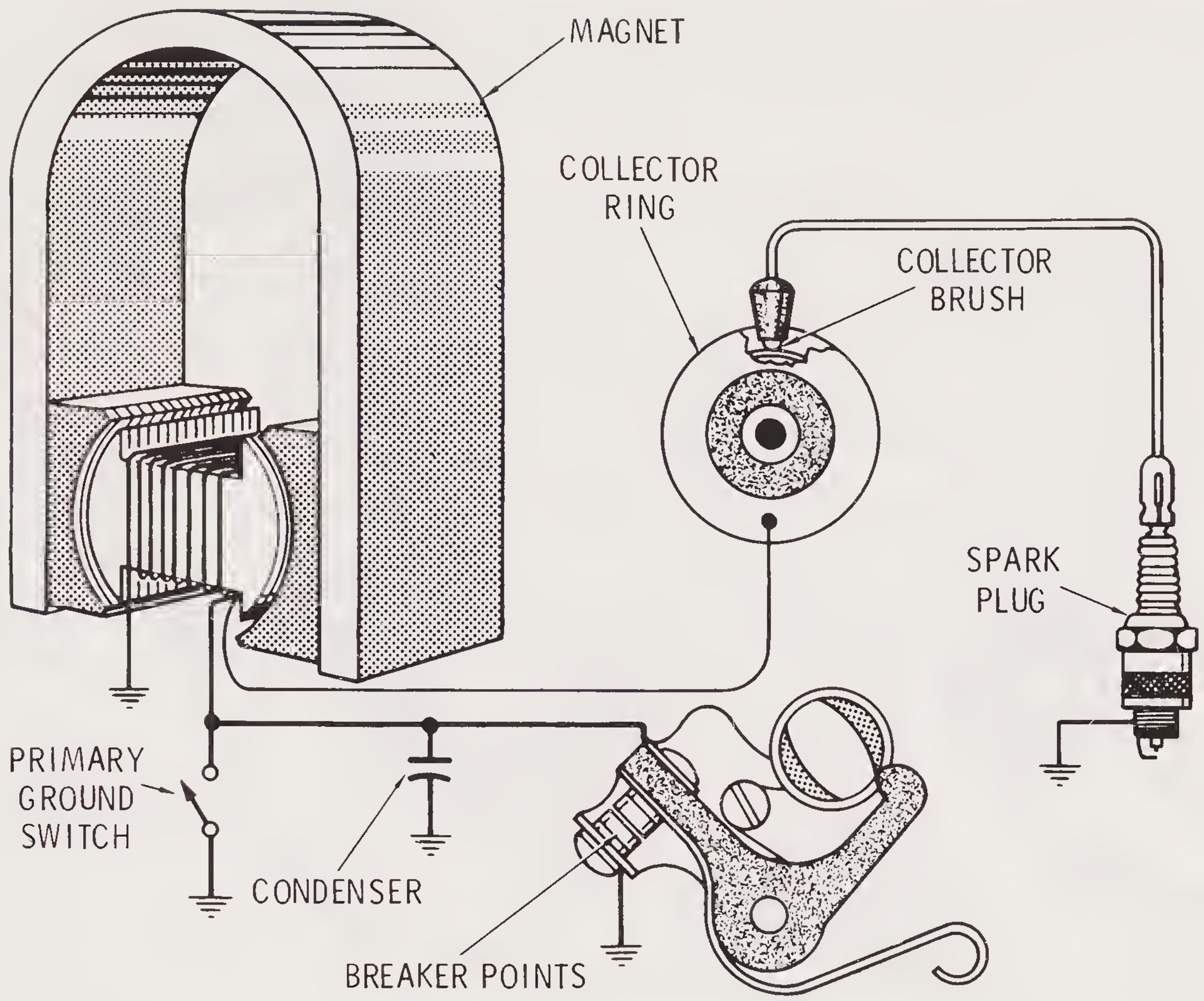



**Fig. 16-14. Rotating-conductor magneto wiring diagram.**

## Spark Action

Voltage requirements at the spark gap in the engine cylinder, as noted in the battery ignition system, is estimated at 10,000 volts. The problem when magnets are used is to raise the low voltage induced in the conductor to the required high voltage. This is accomplished in a way similar to that used in the battery ignition system.

The armature winding is connected to the primary winding of an ignition coil. When the current in the primary winding or conductor is at its maximum flow, the circuit is suddenly broken, collapsing the electromagnetic field set up in the primary circuit as the result of current flow. The lines of force in the field collapse at an extremely high rate of speed across the secondary winding, which is made up of many turns of fine wire, whereas the primary winding is composed of relatively few turns of heavier wire.

This rapid movement of lines of force across the secondary

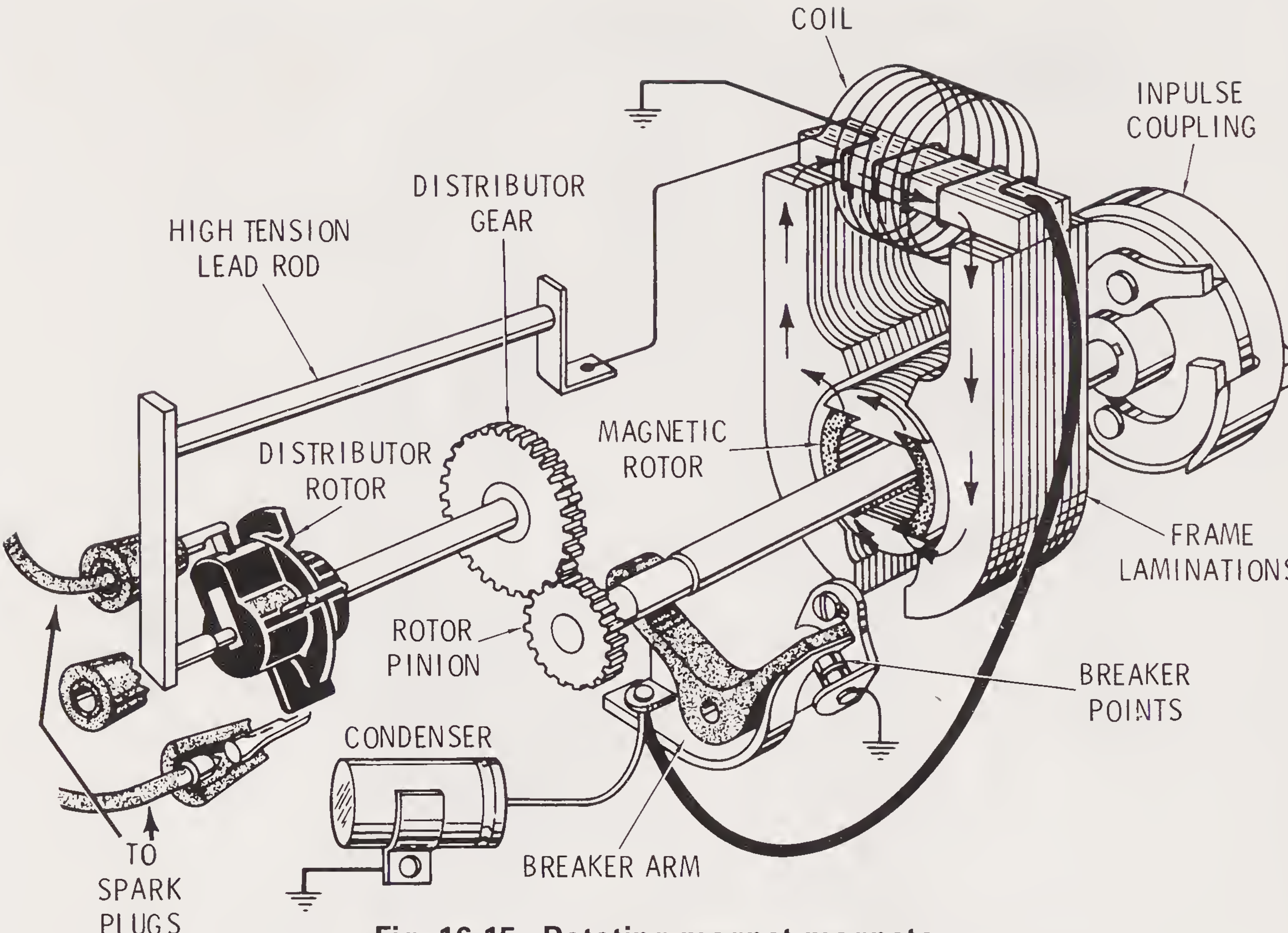



Fig. 16-15. Rotating-magnet magneto.

winding induces a momentary high voltage in the secondary winding, in proportion to the ratio of the number of turns of the two windings. It is in this manner that sufficient high voltage is obtained to create the spark strength necessary to ignite the charge in the engine.

## Breaker Points

The interrupting device that usually breaks the primary circuit at the moment the high-voltage spark is desired consists of a set of breaker points (Fig. 16-15). As noted in the illustration, one end of the primary winding is connected to ground and the other end is connected to the insulated breaker point. When the points are closed, the circuit is completed through them to ground. When they are open, the circuit is broken. Lobes on a cam actuate the breaker points, interrupting the primary circuit and timing the

induction of maximum voltage in the secondary circuit. The cam is mounted on either the armature or the rotating magnet.

## Condenser Function

The condenser inserted in parallel with the breaker points has the same function as in the battery ignition circuit. That is, it absorbs the self-induced voltage produced in the primary circuit by the collapsing magnetic field. In other words, when the primary circuit is interrupted, the condenser receives the surge of current and, on discharging, reverses the normal current flow. In this manner the condenser hastens the collapse of the magnetic field around the primary winding and increases the induced voltage.

## Distributor

The distributor rotor (Fig. 16-15), which controls the proper ignition timing, is fastened to the distributor gear. It is driven by a smaller gear (rotor pinion) located on the drive shaft of the rotating magnet or armature, depending on the type of magnets used. The ratio between the two gears is such that the distributor cylinder is always driven at one-half the crankshaft speed with four-stroke engines, and at the same speed in two-stroke-cycle engines. This ratio insures that each cylinder will be fired at the correct moment of the engine cycle.

With reference to Fig. 16-15, it will be noted that one end of the secondary winding is grounded to the primary, while the other terminates at the high-tension lead rod. The high-tension voltage developed in the secondary coil passes through the lead rod to a carbon brush and then internally through the distributor rotor to the surface electrodes. The rotor is timed so that these electrodes will line up with other electrodes on distributor blocks to which spark plug leads are connected.

## Edge Gap

The edge gap or edge distance may be defined as the distance between the pole shoe and the edge of the magnet rotor at which

point it is most desirable to interrupt the primary circuit in the high tension coil for maximum field strength.

This exact distance is determined by the magneto manufacturer using electrical measuring instruments and, after proper determination, becomes a service specification. For maximum spark strength, the primary contacts should just start to open when the magnetic rotor is at the specified edge gap distance.

## Timing

In magneto installations the timing can be varied within certain limits, by manual rotation of the breaker plate as illustrated in Fig. 16-16. The amount of advance or retard obtained by this method, which does not change the relationship of the cam with respect to the rotating magnet, is limited.

This limitation is due to the fact that the spark strength falls very rapidly as the points open farther away from the position of maximum field strength.

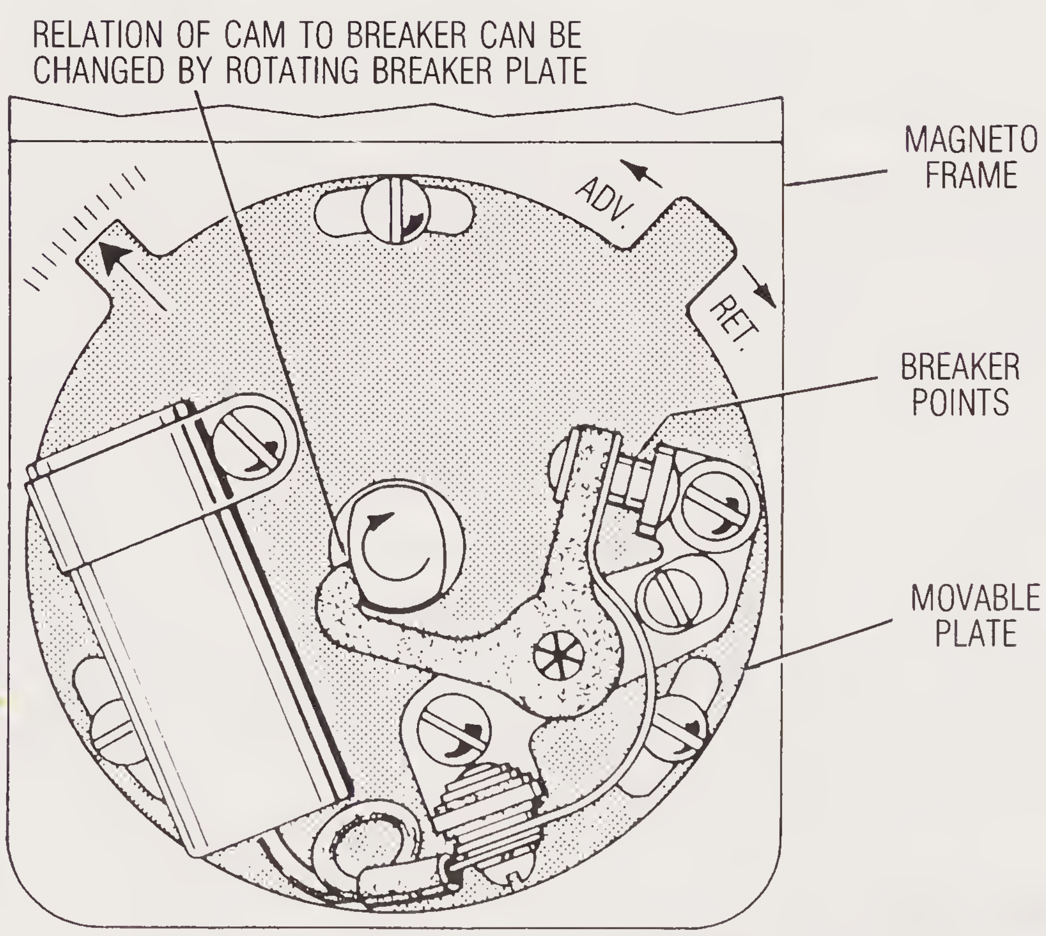



**Fig. 16-16. Adjusting spark advance.**

## Impulse Couplings

The function of the impulse coupling in magneto installations is to increase the spark strength at starting by a temporary increase in the rotative speed of the magnetic rotor at that point in the cycle where ignition should occur. This temporary assist is necessary, since the spark strength of the magneto is directly proportional to the speed of rotation of the magnetic rotor, which is weakest at cranking speed.

## Flywheel Magnetos

These are of the rotating-magnet type and are used exclusively for ignition on small internal combustion engines such as those used on outboard motors, lawn mowers and similar applications. Flywheel magnetos are commonly used on single-cylinder engines, although they are occasionally used on two- and four-cylinder engines as well.

In the typical flywheel type (Fig. 16-17), the magneto is a self-

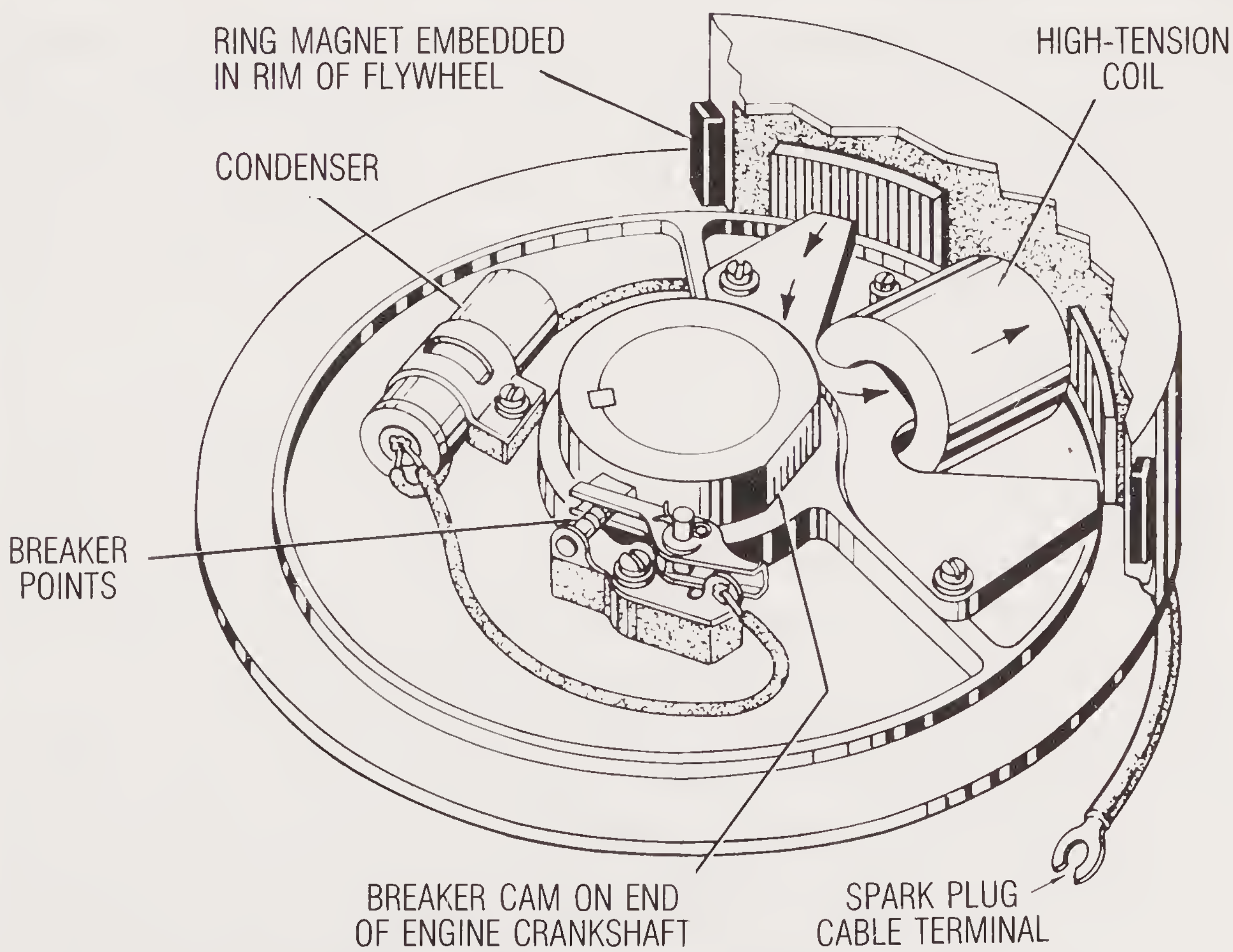



**Fig. 16-17. Typical flywheel magneto.**

contained electrical generating unit consisting of an armature plate with ignition coil and lamination assembly, condenser and breaker mounted on it. A permanent magnet built into the flywheel completes the assembly.

In operation, as the permanent magnet poles pass over the pole shoes of the coil laminations, a magnetic field causes a current to flow through the primary winding of the coil. This current is normally grounded through closed breaker points.

When the breaker points open, actuated by a cam on the crankshaft, the flow of the primary current is broken and the magnetic field about the coil breaks down instantly. As the current tends to continue flowing, the condenser, which is connected across the breaker points, momentarily absorbs this current and hastens the collapse of the magnetic field by creating a high-frequency oscillation in the current. The condenser also reduces pitting of breaker points by absorbing any sparking across them.

## Breakerless Magnetos

Many new small engines have, like modern automobiles, changed to electronic breaker-pointless ignition systems. They are usually termed electronic, solid-state or pointless ignition. The operating principles are basically the same as the battery-operated system except that all power for the control unit must be supplied by the magneto's primary circuit and the magneto magnets and primary circuit are used to replace the sensor.

# CHAPTER 17

# Spark Plugs

By definition, a spark plug is a device whose duty it is to create a spark between its electrodes and ignite the fuel charge in the combustion chamber. With reference to Fig. 17-1, the spark plug consists of a center electrode which is connected to the ignition coil secondary through the distributor as shown in Fig. 17-2.

The center electrode is insulated from the spark plug shell by means of a molded insulator. The side electrode projects from the bottom edge of the spark plug shell and is positioned in such a manner that there is a gap between it and the center electrode. This gap is known as the *spark plug gap*, the size of which is determined by the manufacturer to suit the various types of engines. The spark plug recommended by the manufacturer is generally one that will give the best service under normal operating conditions.

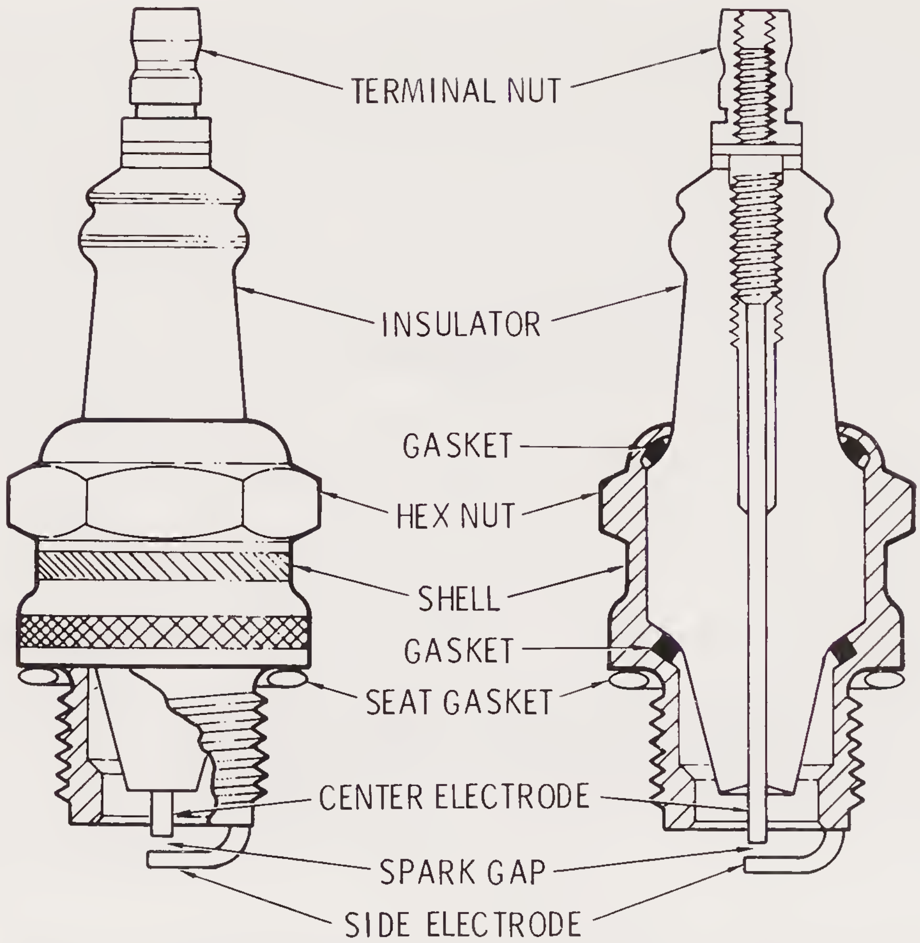



**Fig. 17-1. Construction of typical spark plug with names of parts.**

## Spark Plug Gaps

Spark plug gaps are set in accordance with manufacturers' specifications and range from approximately 0.020 in. to 0.080 in. The size of the gap depends on the engine compression ratio, the ignition system and the characteristics of the combustion chamber. In modern high-voltage ignition systems, spark plug gaps of 0.035 in. and larger are common. Advantages of wider gaps are that they permit additional fuel-air mixture to be ignited for better ignition.

## Thread Sizes

The shell of the spark plug is threaded to facilitate the plug's removal for inspection or replacement. Spark plugs are generally made in four thread sizes: 10 mm, 14 mm, 18 mm and 7/8 in., to fit the corresponding sizes in the cylinder head.

## Heat Range

Modern spark plugs are designed for perfect functioning at certain predetermined temperatures. They are designed this way because

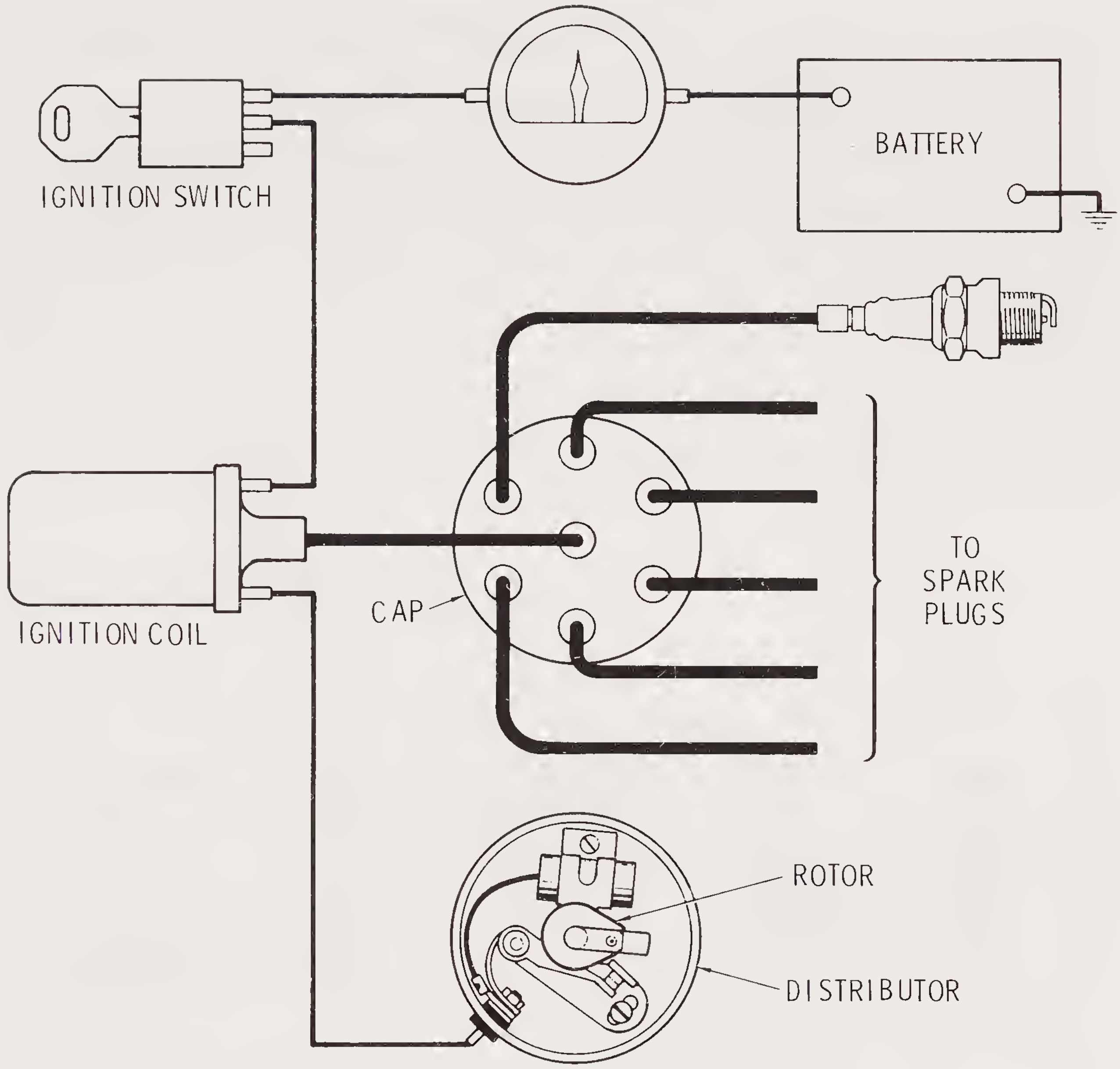



**Fig. 17-2. Typical battery ignition circuit.**

different engines run at different temperatures. The temperature of an engine varies with its revolutions per minute (rpm), load and design.

Thus, engines carrying heavy loads at high speed will run hotter than similar engines carrying light loads. Engines subjected to hard work for an extended period of time will ordinarily operate better and give longer spark plug life if operated with a colder plug. Spark plug manufacturers provide for these conditions of cold or hot engines by making plugs with longer insulators for use in cold engines and shorter insulators for use in hot engines.

Fig. 17-3 illustrates the path the heat must take from the tip of the spark plug to reach the water jacket of the engine. The longer the path the hotter the plug.

As a guide for proper plug selection, manufacturers employ

certain code numbers. Thus, the numerals in each plug number indicate the heat range.

Also, the installation of a *cold* plug in a low-speed engine will result in consistent fouling, while the installation of a *hot* plug in a high-speed engine will result in preignition. In extreme cases, the plug may become hot enough to result in damage to the piston and cylinder head.

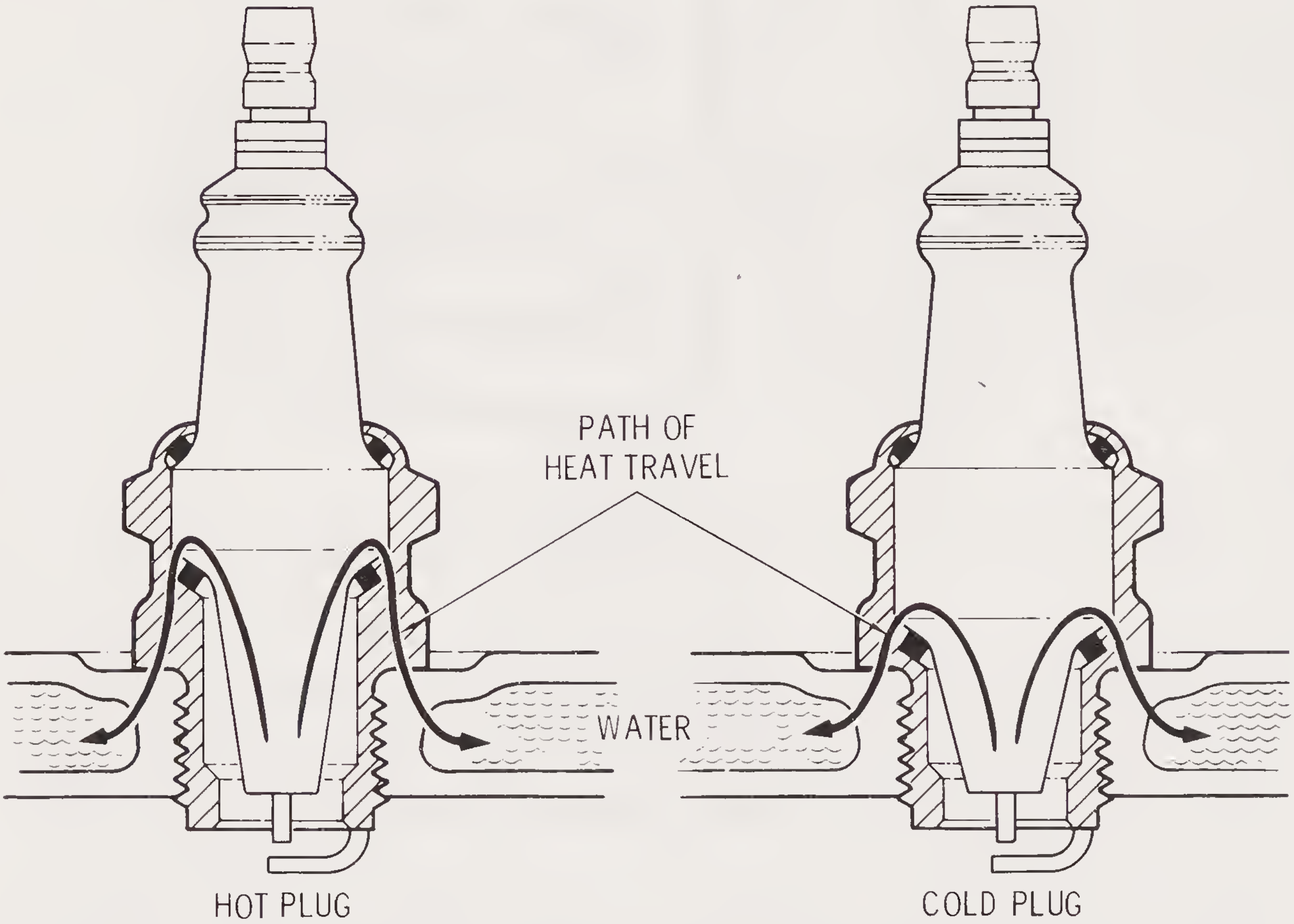



**Fig. 17-3. Hot and cold spark plugs.**

Many modern spark plugs are designed to operate over a wide heat range. They are designed with insulators that protrude above the end of the threads and are termed *extended-tip* or *insulator-type* plugs. The advantage of this type of plug is its ability to operate in a hotter heat range at low speeds and idle, and to operate in a colder heat range at high speeds. This is accomplished by the unprotected portion of the extended insulator. As engine speed or load increases and the throttle is opened, the cool intake mixture is allowed to enter the cylinder faster, striking the unshielded portion of the insulator and cooling it.

## Resistor-Type Spark Plugs

The advantage of modern resistor-type spark plugs is twofold. The resistor, made of temperature-resistant carbon (graphite) and installed in the upper portion of the insulator in series with the center electrode, was originally designed to suppress radio interference produced by the high secondary voltages. The resistor accomplishes this by regulating the spark to a more steady state. By producing a steadier spark and high-voltage current, many of the erratic tendencies of the physical spark as it jumps the plug gap are eliminated. The result is less erosion of the electrode and longer spark plug life.

## Cleaning and Gap Adjustment

Plugs that are in good condition except for carbon or oxide deposits should be thoroughly cleaned and adjusted. To clean plugs, soak them in a carburetor cleaning solvent from 15 to 30 minutes. Thoroughly dry the interior of plugs with compressed air, then scrape out all carbon and oxide deposits from the shells and insulators with a pointed steel scraper. Blow out all residual matter with sandblasting equipment.

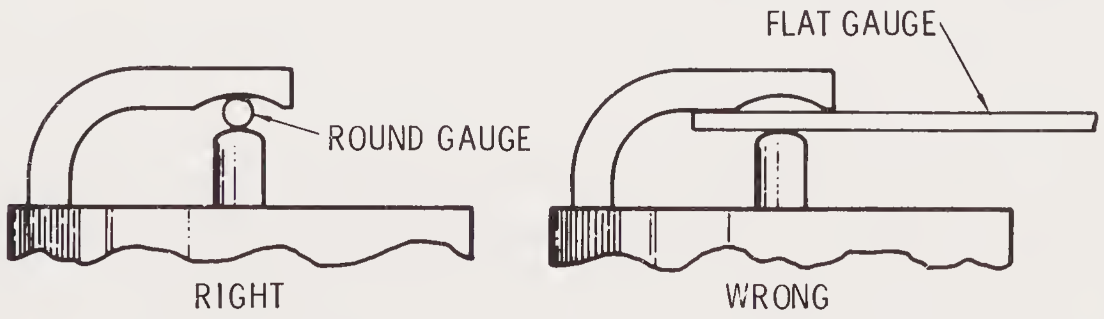



**Fig. 17-4. Correct method of measuring spark plug gap.**

When adjusting spark gaps, use round-wire feeler gauges to check the gap between spark plug electrodes. The feeler gauge should be of the same diameter as the plug gap recommended by the engine manufacturer. Flat feeler gauges will not give a correct measurement. Adjust the gap by bending the side electrodes only; bending the center electrode will crack the insulator. See Fig. 17-4.

Before installing a spark plug, make sure that the spark plug seat in the cylinder head is clean and free from obstructions. It is strongly recommmended that a new seat gasket be used each time a plug is installed. The plug should be screwed into the cylinder head to compress fully the gasket.

CHAPTER 18

# Emission Control Systems

The operation of a vehicle powered by a gasoline-burning, internal combustion engine releases certain gases into the atmosphere which, in sufficient quantity and/or under certain atmospheric conditions, are harmful, and are referred to as air pollutants. Raw (unburned) gasoline releases pollutants by evaporation; an operating engine releases them in its exhaust.

The principal pollutants, for which the government has established acceptable levels of emission, are:

1. *Carbon Monoxide* (CO). A compound consisting of one part carbon to one part oxygen. The combustion process, if complete, produces beneficial carbon dioxide ($CO_2$) instead; poisonous CO is produced when the combustion process is incomplete. It is also formed when raw fuel vapors mix with the atmosphere.

2. *Hydrocarbons* (HC). Compounds of hydrogen and carbon that are a part of gasoline released by evaporation.
3. *Oxides of Nitrogen* ($NO_x$). Compounds of nitrogen and oxygen formed principally by too-hot burning of the air-fuel mixture.

## CLASSIFICATION OF CONTROLS

In theory, there would be no problem with air pollutants if a vehicle were designed to prevent fuel evaporation and to burn completely the fuel it uses under controlled conditions. It follows that the control of emission levels presents two basic problems: elimination of raw fuel vapors and elimination (or reduction to acceptable amounts) of the final-exhaust pollutants. As discussed later, there is one group of *fuel-evaporation controls* to deal with the first problem; the second problem is dealt with in a number of different ways, as follows:

One way to deal with the final-exhaust problem is to provide more efficient combustion during the different conditions of engine operation. Ordinarily, CO and HC pollutant levels become excessive during engine starting and warm-up (especially at cold ambient temperatures), during idling and whenever the engine is decelerated from a high speed.

Cold starting and warm-up increase the levels because choking is required to enrich the mixture and the cold air does not provide thorough vaporization and mixing-in of the fuel. Idling, even with a warmed mixture, can increase the levels because the compression ratio is decreased (less content to be compressed in a cylinder) and a normally advanced spark cannot fire all the reduced-density content. Also, during deceleration, the content density is decreased, leaving a similar slow-combustion condition. Deceleration may be the result of accelerator operation or the change in engine load.

The control of combustion therefore necessitates controls that will effectively maintain a more combustible mixture during the critical engine-operating periods. It also necessitates controls that will retard the spark as needed, and throttle controls to prevent a too rapid depletion of cylinder content.

Car manufacturers have devised a variety of "systems" (also

called "packages") under various trade names to deal with combustion-control problems. Some of these systems involve little more than modifications of the engine and components already familiar; others require the addition of several distinctly new control devices. Later, under the heading "Combustion Control Systems," we will discuss typical systems before discussing typical new devices used in the systems.

Since any unburned or partially burned mixture exhausted from the cylinders must travel through the exhaust manifold, pipe and muffler before entering the atmosphere, another method of reducing CO and HC emissions is to more nearly complete the combustion process for gases being exhausted. New kinds of devices are needed to implement this type of control, as will be discussed later under the heading "Combustion Control Systems."

There are two basic ways of controlling nitrogen oxides emissions: (1) by limiting the heat rise within the cylinders, and (2) by limiting the spark advance to periods of engine low-load operations (when performance is normally at its peak). Method 1 requires new and different kinds of controls; method 2 is based on new controls similar to the preceding spark controls. Both are discussed under the heading "$NO_x$ Controls."

## Final-Exhaust Controls

Insofar as all other methods have practical limitations, the final control for CO and HC emissions is to chemically convert these emissions, at the point of final exhaust just ahead of the muffler, into harmless compounds. This type of control will be discussed under the heading "Catalytic Converters" at the end of this chapter.

## Fuel Evaporation Controls

Several different methods are used for controlling gasoline evaporation from the fuel tank, lines and crankcase. Generally, the controls are combined into one system whereby fuel tank vapors are vented into a storage container, and combined fuel tank and crankcase vapors are then "fed" into the intake manifold to mix with the air-fuel mixture. Such a system typically requires several vehicle modifications and new devices.

## Fuel Tank and Lines Modifications

The vented fuel tank cap generally has been replaced by a *nonvented cap*. Prior to this change, a vented (to the atmosphere) cap has been used to prevent internal pressure, created by heat expansion of the fuel vapor, from bursting the tank and to prevent the vacuum created, when the fuel pump sucks fuel from the tank, from causing the tank to be collapsed by atmospheric pressure. To obviate these problems in an unvented tank, the tank cap may be fitted with a two-way check valve that will open at predetermined pressures in case pressures on the tank become excessive, while a vent line from the carburetor or air intake supplies normal air to replace used fuel. The tank may also be designed to have an *expansion chamber* or *area* (which cannot be filled with fuel) that is vented.

Because ordinary fuel lines are subject to decomposition, special-material fuel lines are used in the venting systems. Substitution of an "ordinary" vented tank cap will make the system inoperative; substitution of "ordinary" fuel line hoses may clog the system and result in tank bursting or collapse. This can also happen if a check valve incorporated in the tank (or system) malfunctions. See Fig. 18-1.

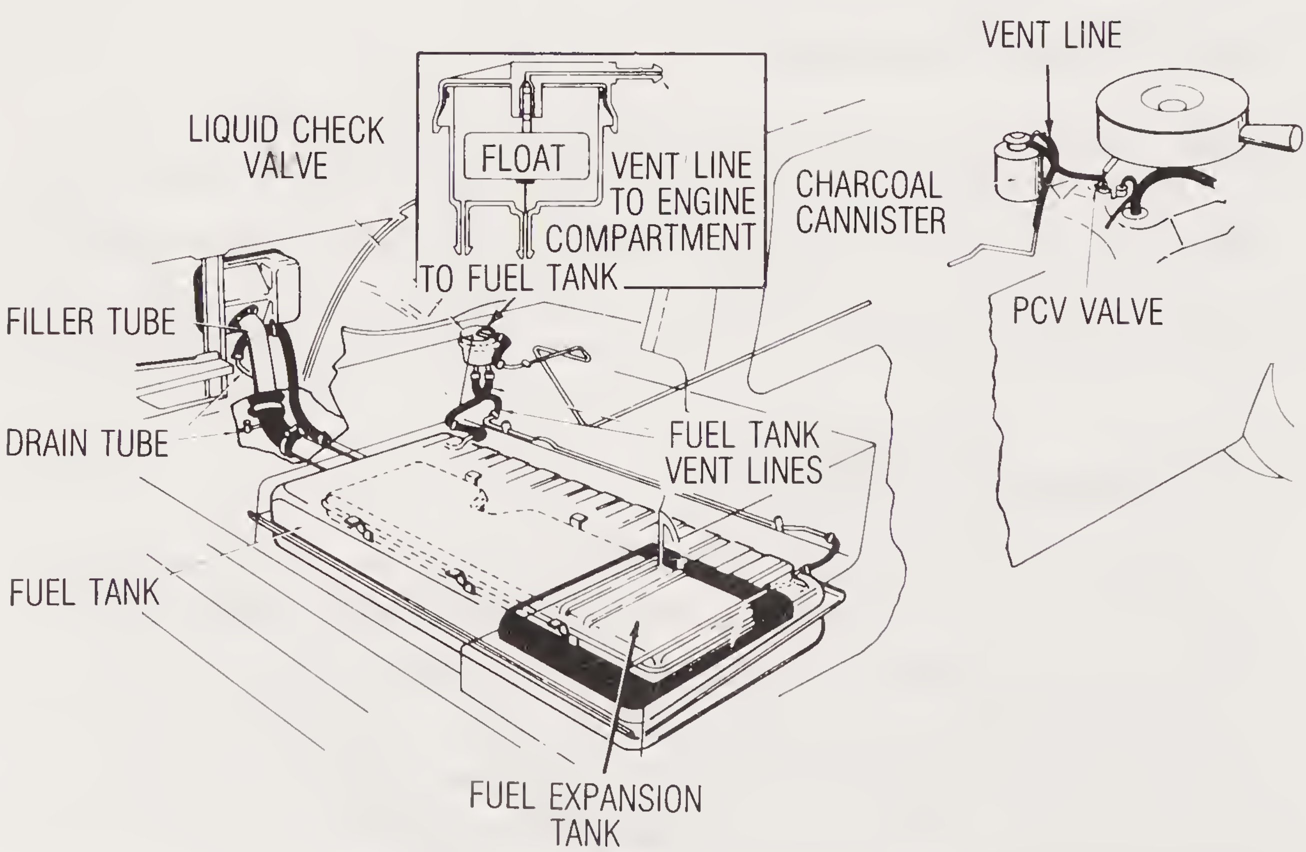



**Fig. 18-1. Tank vapor control system.**

## Tank Vapor Venting

Tank vapor may be vented to the crankcase (to be vented from there as explained later) or to the air intake (to slightly enrich the carburetor mixture). Most systems include a *liquid check valve* (also called a *liquid/vapor separator*) in the vapor line, which functions to prevent raw fuel from entering the system (it has bypass tubes through which any raw fuel splashed or sucked into the system is returned to the tank). Most systems also have a *fuel-vapor-storage canister* in which the vapors, arising from the tank when the engine is not running, are stored until they can be drawn into the engine and burned. This canister may be filled with charcoal or carbon granules (which absorb and hold the vapors until a "draft" carries them off ) and may or may not have check-valve-controlled vents to other parts of the system. On the whole, the purpose is to collect tank vapors, then disperse them as intended.

From the canister, vapors are dispersed either to the crankcase (as already noted) or directly into the air intake of the carburetor.

## Crankcase-Vapor Venting

Unburned fuel that leaks past the piston rings into the crankcase also presents a vapor evaporation problem. In old engines, the crankcase is vented to the atmosphere to dissipate these vapors. In a pollution control system, vapors are not permitted to escape to the atmosphere. Instead, air is circulated through the crankcase, entering either by way of a tube from the air intake or through an opening in the oil-filler cap, and is directed by tube to the manifold side of the air intake. Most systems have a spring-loaded valve that remains closed when manifold vacuum is low, but opens whenever manifold vacuum is sufficient and also regulates the volume of vapors allowed to enter the cylinders.

This is called a *PCV (positive crankcase ventilation) valve.* By its operation the crankcase vapors (mixed with air and perhaps with fuel tank vapors) are introduced into the air-fuel mixture during most periods of engine operation. The carburetor must be adjusted for this mixture enrichment, and any malfunction in the PCV system will adversely affect the mixture and engine performance (Fig. 18-2).

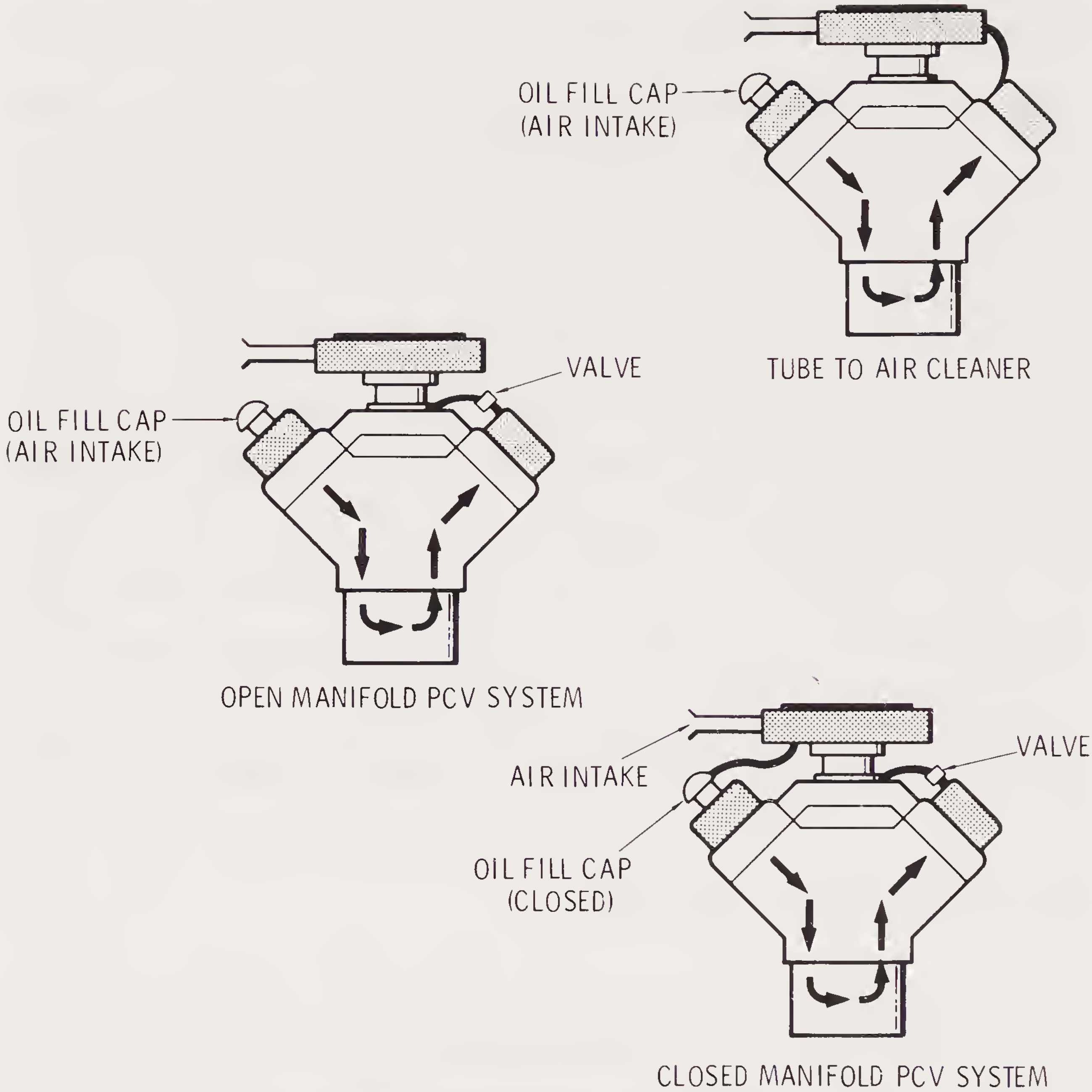



**Fig. 18-2. Typical PCV installation.**

## Combustion Control Systems

As previously noted, various systems (or "packages") have been created to minimize CO and HC emissions resulting from the combustion process. Although different types and/or arrangements of individual control devices are used, all the systems are designed to eliminate, insofar as is possible, mixture enrichment beyond the 15 (air) to 1 (fuel) ratio that provides a satisfactorily complete combustion under normal running temperature conditions. All systems also include some type of spark-advance control together with, in many cases, throttle-position controls and other accessory and/or engine modifications.

Air-fuel mixture controls that are used for controlling the extent of mixture enrichment can be classified as follows:

1. *Cold engine starting controls* that operate to assure a rapid choke opening after a cold engine has been started. Two basic types are in use: an *electric assist choke* and a *choke hot-air modulator.*
2. *Air-intake temperature controls* that operate to provide rapid warming of the mixture after a cold start so as to assure soon-as-possible maximum vaporization of the fuel. Practically all systems have some form of *thermostatic air-intake control* whereby exhaust gases are used to preheat air entering the air cleaner.
3. A *control that circulates hot exhaust gas* through the intake manifold to hasten mixture warm-up as above.
4. A valve that admits *additional mixture into the intake manifold* during high-speed deceleration (which, in effect, lowers manifold pressure) to reduce the enrichment of the mixture caused by high manifold vacuum at the carburetor idle-speed fuel nozzle.
5. A *faster idle-speed throttle stop* that serves two purposes: (a) reduction of fuel enrichment at idle, by admitting proportionally more air past the throttle; (b) smoother engine idling on the leaner mixture.
6. *Recalibration of the carburetor* to provide a leaner mixture, either for all operating conditions or for certain operating conditions such as at idle and slow speed. Also, a method of eliminating excessive fuel from being drawn through the carburetor idle circuit during rapid deceleration.
7. Substitution of a *fuel injection system* (instead of a carburetor). A controlled fuel injection system provides better (than carburetor) mixture control for various operating conditions.

Spark timing controls used to improve combustion under different operating conditions can be classified as follows:

1. Overriding *distributor vacuum-advance controls* that retard the spark from conventional setting for idle operation or, at

least, for idle operation except during cold-engine operating periods (when an advanced spark is needed for combustion of the enriched mixture).

2. *Vacuum-advance controls* that either: (a) delay conventional spark advance during acceleration, and/or (b) provide an advanced spark or a more slowly retarded spark during deceleration. A conventional distributor advances the spark in relation to engine rpm and throttle opening. During a fast acceleration, the resulting too-rapid spark advance tends to increase the rpm disproportionately to the throttle opening, resulting in overenrichment of the mixture. During deceleration, the closed (or closing) throttle cuts off the engine's air supply instantly (or too rapidly), causing insufficient spark timing.
3. *Redesign of the distributor centrifugal-advance mechanism* to delay and/or retard its operation—to accomplish one or more of the foregoing purposes.
4. *Ambient- or coolant-temperature sensing controls* that are used in conjunction with the spark-retarding controls to advance the spark when engine (or air) temperature is below a predetermined degree—and also, in some cases, whenever the temperature exceeds a (different) predetermined degree. Advancing the spark for a cold engine increases the rpm and (as previously mentioned) enriches the mixture to improve vaporization during warm-up; advancing it when an idling engine becomes overheated reduces the temperature by increasing the idle speed.
5. Substitution of *computerized or electronic ignition* for the conventional distributor. Such a multicontrol system can accomplish some or all (depending upon design) of the foregoing purposes.

*Throttle control* generally consists of an increased *fast* idle setting (obtained by resetting the idle-stop screw), together with a solenoid control that slows return of the throttle to idle position during high-speed deceleration. The faster "curb" idle setting allows the engine to run cooler on a leaner idle mixture and/or with a retarded spark, and also avoids rough idling and carburetor icing.

Retardation of deceleration helps curb the mixture enrichment previously explained. This is also accomplished (in some cases) by controls that bypass a measured amount of mixture around the throttle during deceleration.

Another throttle control frequently used is one that will positively close the throttle when the ignition switch is turned off. A thinned (hot-burning) mixture and a faster-idle throttle position can result in the engine continuing to run a short time after the switch is off (called *dieseling*). By providing an effectively closed throttle setting and a device (*idle-stop solenoid*) to return the throttle to this position with the turning off of the switch, dieseling is eliminated.

Because prolonged idling (even "fast" idling) with a thinned mixture and/or retarded spark can cause engine overheating, in some cases the coolant system is modified, either by complete redesign or by recalibration of the coolant thermostat. Use of a no-lead fuel together with a reduced compression ratio also reduces the pollutant levels.

Combustion control systems generally incorporate several of the controls mentioned above. For instance, most systems include either an electric assist choke or a choke hot-air modulator, some type of thermostatic air-intake control, together with one or two of the spark advance controls plus, in some cases, throttle and coolant-circulation controls. On the other hand, several systems rely more on recalibration of the carburetor (in one case, to provide an 18 to 1 air-fuel ratio), recalibration of the distributor, cooling-system modifications, and just one control device (a vacuum-advance control valve) to control—and retard—distributor vacuum advance during idle, slow speed and decelerations.

*Electric assist chokes* are designed to prevent prolonged enrichment of the mixture at engine starting and warm-up. This is an integral, nonserviceable unit attached to the carburetor that has *no* effect on conventional carburetor calibrations or adjustments. It serves only to hasten opening of the choke. See Fig. 18-3.

A typical unit contains a *thermostatic spring*, a bimetal *switch* and a *heater*. It is connected to the vehicle electrical system so that current is supplied to the switch whenever the ignition switch is at start or on. At temperatures below 60°F. the switch remains open, but at about 60–65°F. it closes to pass current through the heater. Warming of the heater moves the spring to pull the choke open.

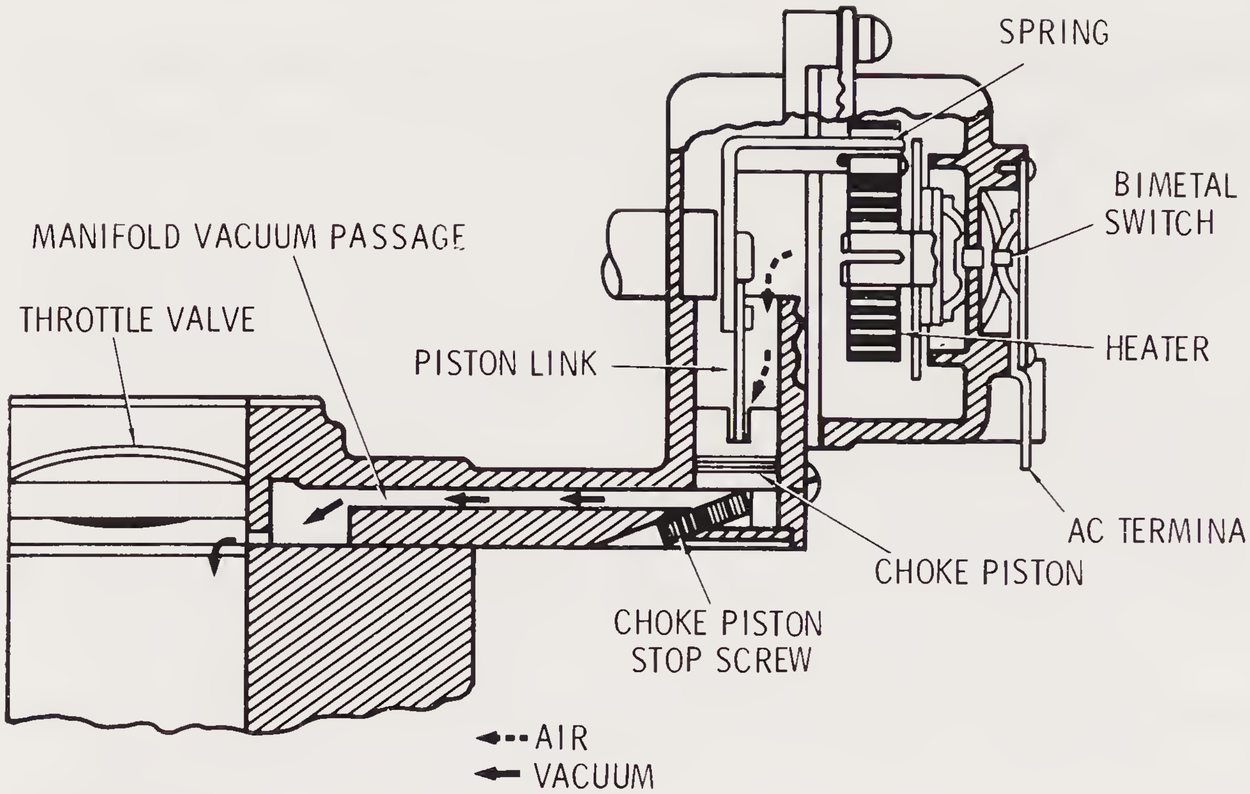



**Fig. 18-3. Typical electric assist choke.**

From cold start at 60°F. or higher, the choke opens faster, thus assuring a leaner mixture much sooner than with a carburetor not so equipped. At ambient temperatures below 60°F. the time is extended until engine heat closes the switch.

Some units have a second bimetal switch that opens when engine temperature reaches approximately 110°F. to open the circuit of the first switch and turn the heater off since engine heat makes it unnecessary. Others are designed to provide two or more stages of choke opening.

**Note:** Cars with fuel injection are fitted, instead, with a *fast-idle valve*, which functions in a similar manner.

## Choke Hot-Air Modulator

This system controls the choke (for starting and warm-up) by sensing the temperature of the air being drawn through the air cleaner. Air drawn through a *modulator* (a *bimetallic valve) located at the bottom of the air cleaner is heated in a heater coil* located in the exhaust manifold, and is passed through a bimetallic *thermostatic coil*, which is also subject to manifold vacuum and which controls the choke. See Fig. 18-4.

At temperatures below approximately 68°F. (ambient), the

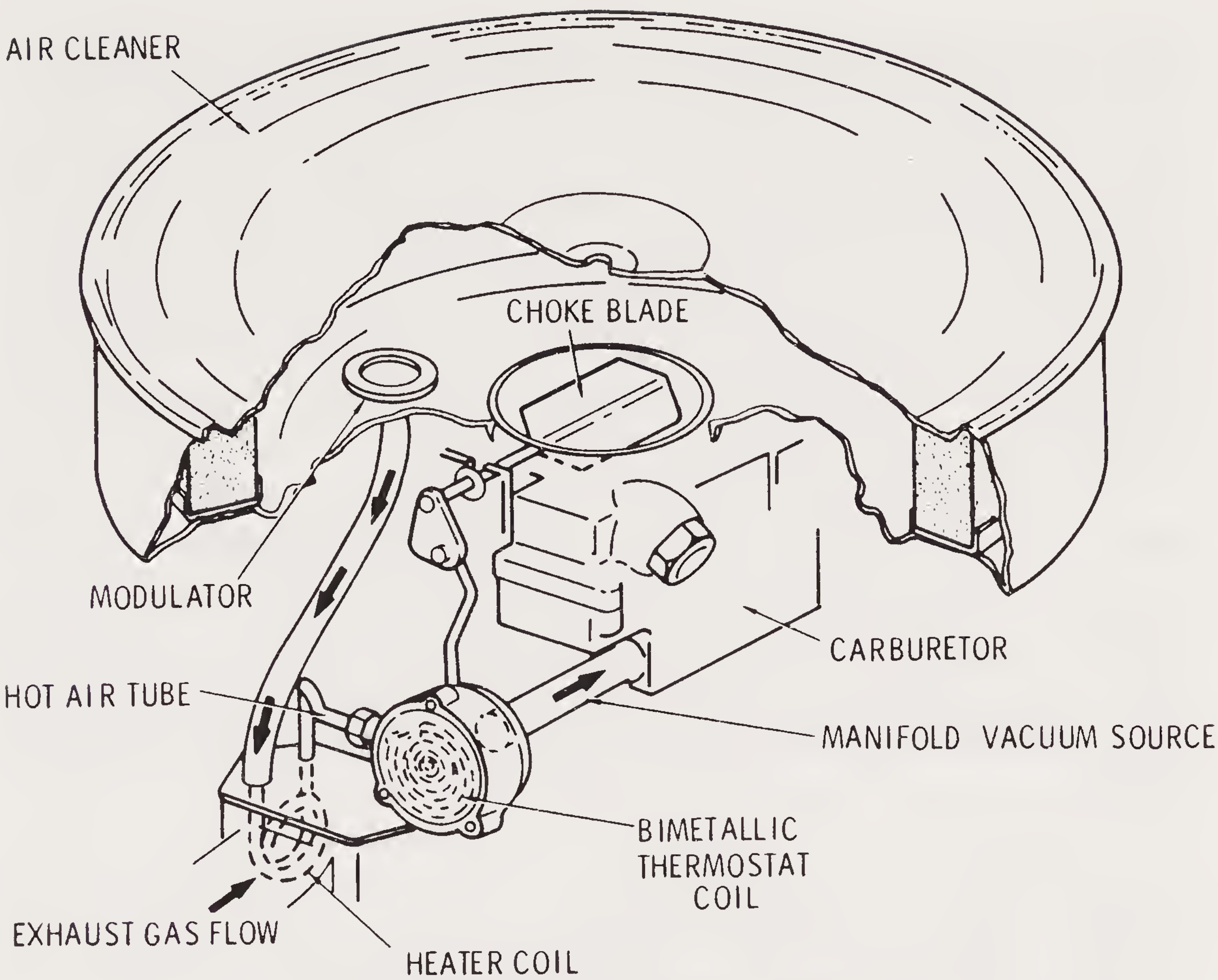



**Fig. 18-4. Hot-air choke system.**

modulator opening is negligible to permit very little air to be heated by the heater coil and affect the bimetallic coil, which consequently holds the choke open. At higher ambient temperatures the modulator opens to pass more air; also, as exhaust temperature rises, the heater coil increases the temperature of the air to the bimetallic coil. Thus, choke opening is hastened both by a higher ambient temperature and by engine warm-up.

## Thermostatic Air-Intake Control

The idle adjustment of a carburetor must normally be somewhat richer than the high-speed adjustment, to compensate for the lower temperature of the mixture at starting and warm-up. By hastening the mixture temperature rise, thermostatic control of the intake air (into the air cleaner) permits a leaner carburetor idle-speed adjustment.

The preheated air needed to rapidly increase the mixture tem-

perature is drawn through a *shroud* (an encircling duct) around the exhaust manifold, and is conveyed by an air duct to a *snorkle* (a projecting attachment) on the side of the air cleaner. This snorkle, or the side of the air cleaner, also has another opening through which unheated air (referred to as *under-hood air*) can enter. Unit controls are designed to allow only heated air to enter when the under-hood air temperature is above a predetermined degree (generally 100°F. or more), and to switch from heated to under-hood air at higher temperatures. See Fig. 18-5.

The simplest control is a thermostatically operated air-duct valve arranged to close off the under-hood air passage into the snorkle, then to open this passage while closing off the heated-air passage. A *spring* holds the valve in its first position; a *thermostat* moves it to its second position as the air temperature rises, and holds it fully open whenever the temperature exceeds approximately 130°F.

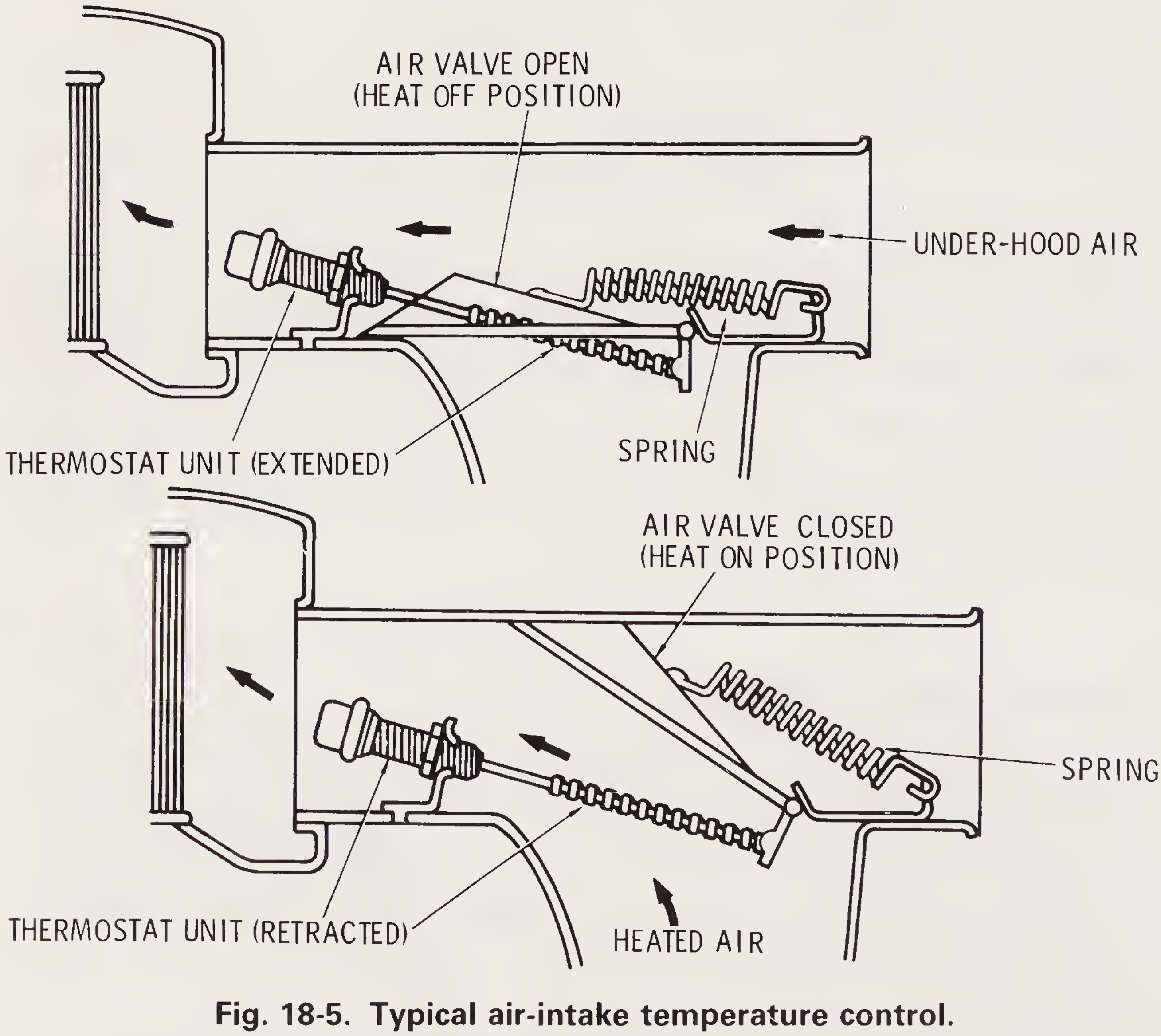



**Fig. 18-5. Typical air-intake temperature control.**

In order to provide sufficient air for the mixture (should the engine be accelerated while still cold), a *vacuum override motor* (or similar) may be used. The type illustrated (Fig. 18-6) operates the foregoing valve and is attached to the snorkle. Another type of control used is a separate unit that opens into the air cleaner through which additional fresh air can be allowed to enter. In either case, the "motor" is a spring-loaded diaphragm exposed (through a hose) to the intake manifold and arranged to operate a lever connected to the air-duct valve. During acceleration, the decrease in manifold vacuum moves the diaphragm against its spring, and the lever overrides the thermostat unit to open the air-duct valve and admit more under-hood air into the air cleaner.

More complicated units have a vacuum motor (Fig. 18-7), instead of a thermostatic element, to operate the air-duct valve—and a *bimetallic switch* (or *sensor*) controls the vacuum operation of the motor. This switch is installed inside the air cleaner and is connected to the vacuum hose between the manifold and motor. By sensing the air temperature, it opens or closes the vacuum hose, thus serving the same purpose as the thermostatic element. Additional air for hard acceleration is automatically assured with this system, since reduced manifold vacuum caused by the open throttle allows the vacuum motor to open.

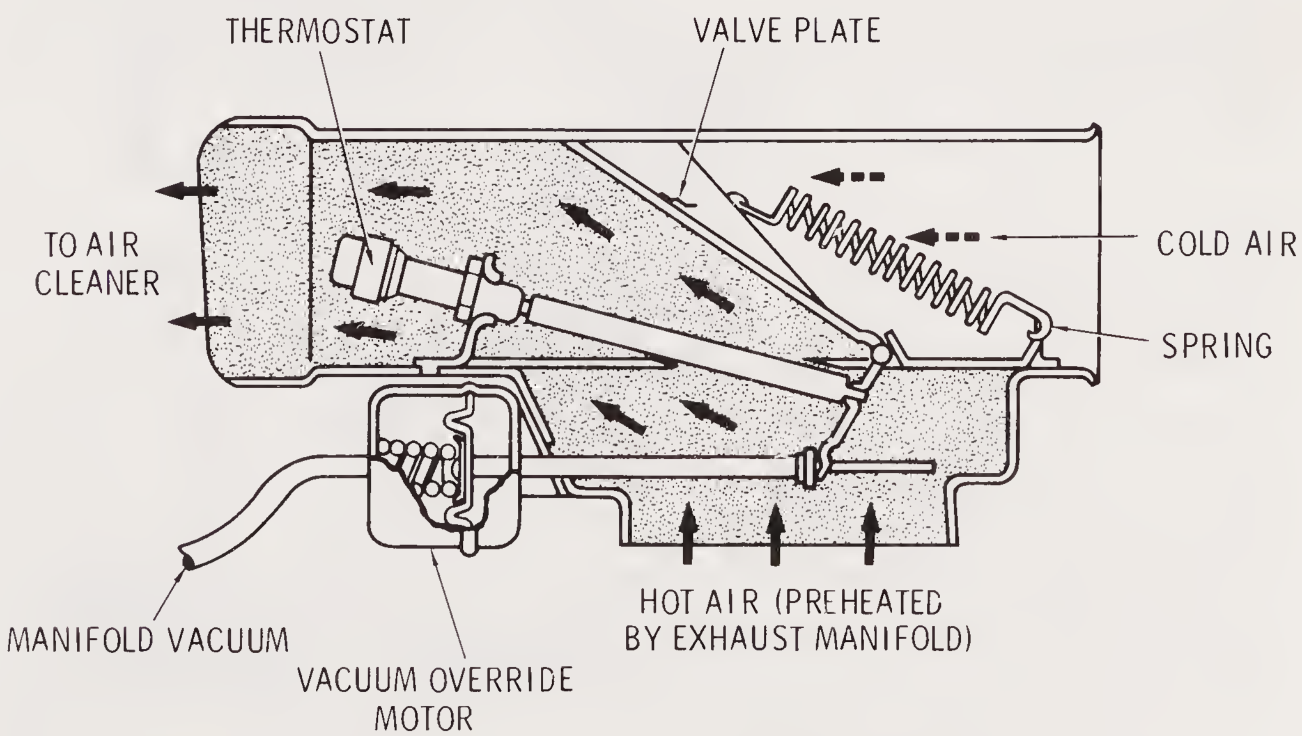



**Fig. 18-6. Vacuum override system.**

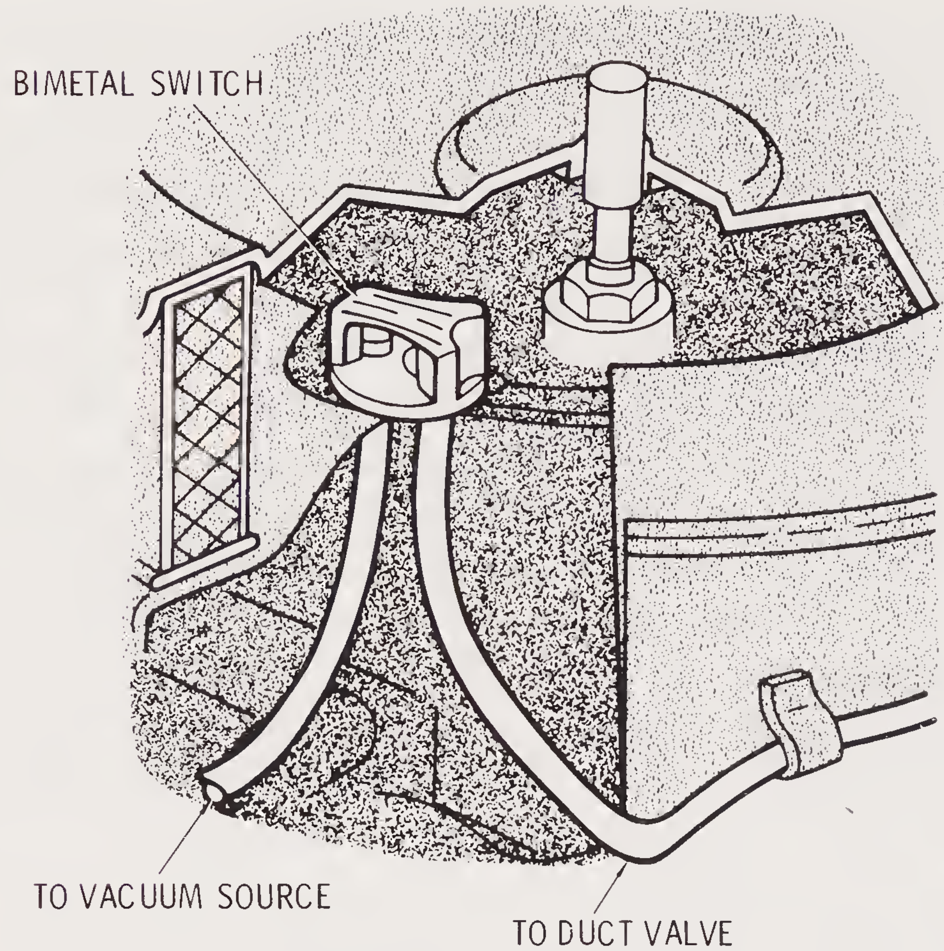



**Fig. 18-7. Typical bimetal sensor switch.**

Some units have two (instead of one) air-duct valves (called *doors*) to control separately the flow of hot (heated) air and cold (under-hood) air into the air-cleaner snorkle. These doors are connected to the motor to work in opposition, so that one opens as the other closes.

## Heat Control Valve

A different method of accomplishing fast fuel-air mixture warm-up is the passing of exhaust gases through a pipe in the intake manifold and/or to the base of the carburetor at *below* a predetermined temperature. This is accomplished by a *heat control valve (HCV)* or an *early fuel evaporation valve (EFE)* located between the exhaust manifold and exhaust pipe with a bypass through the intake manifold. The valve may be operated by intake manifold vacuum through a coolant-sensing switch that closes the vacuum line to open the valve when engine coolant temperature reaches the desired temperature, or by a bimetallic spring mounted on the exhaust manifold.

## Deceleration Valve

Mounted on the intake manifold, this valve operates to meter an additional amount of air-fuel mixture or fresh air into the manifold during high-speed deceleration. The unit contains a spring-loaded valve that is opened by movement of a diaphragm. During deceleration, the high manifold vacuum serves to move the diaphragm. With the valve open, additional mixture or air is drawn from the throttle side of the carburetor (through a connecting tube) into the manifold. The valve closes as manifold pressure drops with the completion of deceleration. See Fig. 18-8.

## Idle-Stop Solenoid (Anti-Diesel Solenoid)

Because of a higher operating temperature when the mixture is leaned, as previously explained, together with a fast idle setting, an

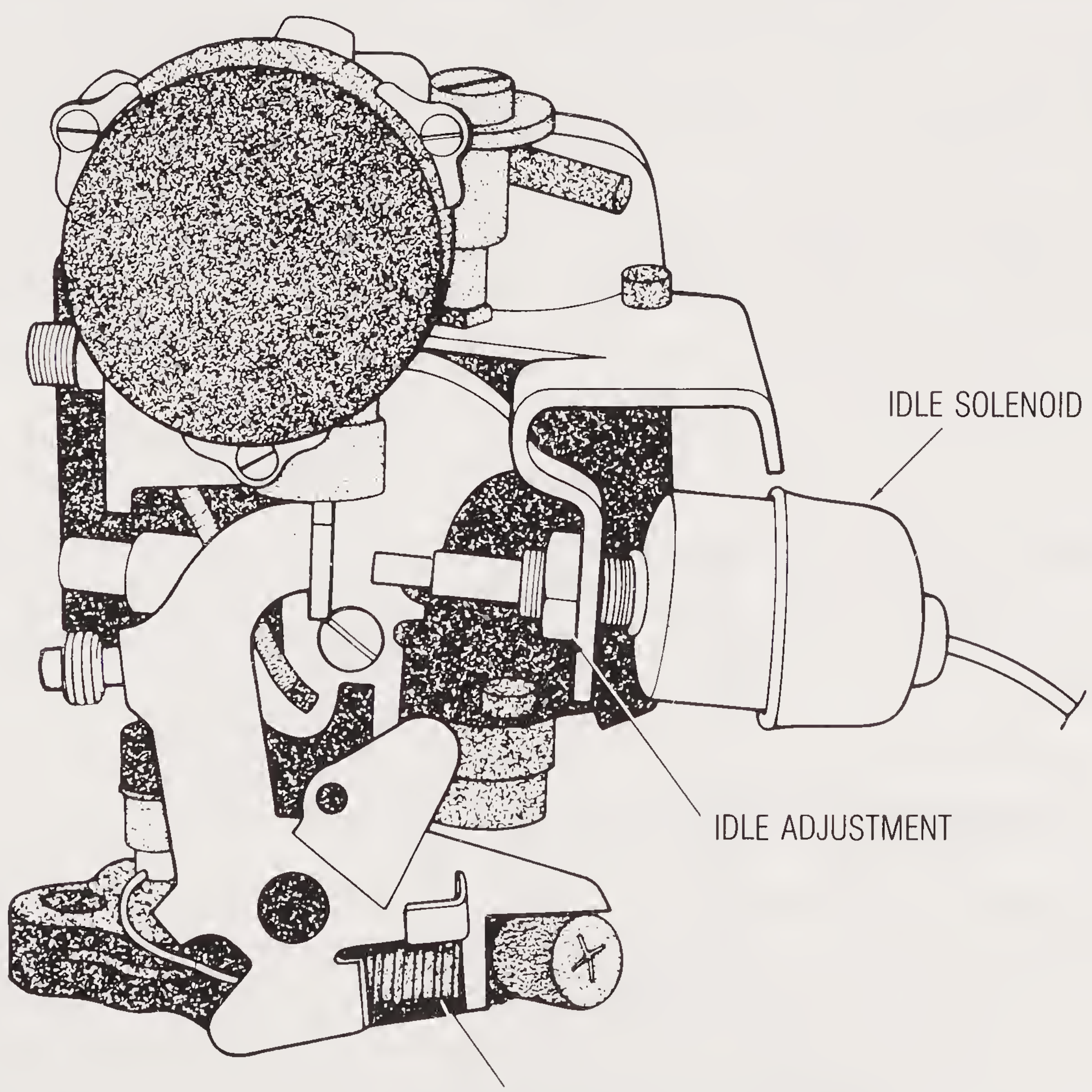



**Fig. 18-8. Idle-stop solenoid.**

engine tends to continue running for a short time *after* the ignition switch is turned off (called *dieseling*). To prevent this, a solenoid, energized by the primary circuit of the ignition switch, is mounted on the carburetor and arranged to positively return the throttle to a predetermined "off" position when the ignition switch is off.

When the ignition switch is on (or at start), the energized solenoid's plunger moves the throttle lever up to the (normal) idle-adjustment-screw setting; turning the ignition switch off deenergizes the solenoid so that the plunger moves in, allowing the throttle lever back against a low-idle adjustment screw (at which point the throttle is as nearly closed as it can be without danger of scuffing the throttle bore).

## Distributor Solenoid

This is the simplest device for retarding ignition during idle. A solenoid is mounted so that movement of its plunger, when it is energized, will override the vacuum-advance mechanism and retard the spark timing. The solenoid is energized through electrical contacts on the carburetor throttle stop. Opening the throttle breaks the contacts to permit conventional vacuum distributor advance; therefore, the solenoid does not operate during part-open throttle—and other controls in the system with which this is used set the throttle at part open (fast idle) for cold starting.

A different type of distributor solenoid is used on some engines merely to override other controls so as to retard the spark during engine warm-up. This solenoid is activated when the ignition switch is on and the engine is cold. The solenoid valve is located in a vacuum line to the distributor, which is opened when the engine warms up.

## Dual-Diaphragm Distributor

Idle-speed spark retarding is also accomplished by a distributor having two diaphragm mechanisms. One diaphragm is operated by vacuum taken from the carburetor above the throttle—where the strong vacuum created during acceleration and cruising will serve to advance the spark in a conventional manner. The second diaphragm is operated by vacuum taken from the intake manifold, and

serves to retard the spark during idle when this vacuum is high. See Fig. 18-9.

This distributor mechanism is usually combined with a *vacuum control valve*, the purpose of which is to open a bypass between the manifold vacuum and the conventional advance distributor diaphragm. Installed where it can sense the engine-coolant temperature, this normally closed valve opens whenever prolonged idling overheats the engine. When it is open, the manifold vacuum takes over to advance the spark and allow the engine to run cooler.

## Vacuum-Advance Control Valve

A conventional distributor vacuum-advance mechanism advances the spark during idle and retards the spark during deceleration, due to very low carburetor vacuum at such time. One way to assure the early spark needed for better combustion during deceleration is to use manifold vacuum (which, at this time, is strong enough) to overcome the mechanism spring and keep the spark advanced. See Fig. 18-10.

This is accomplished with a *vacuum-advance control valve*, which is used with a distributor specially designed to provide a

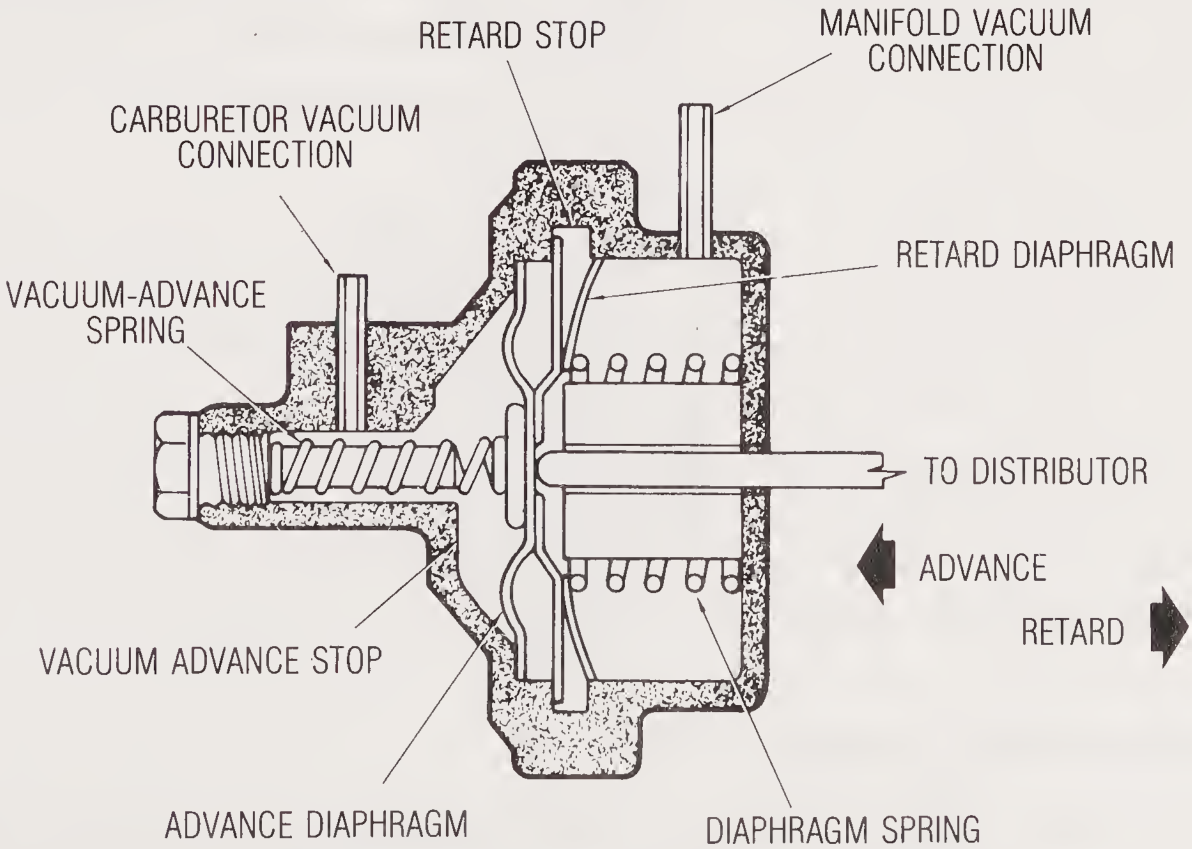



**Fig. 18-9. Dual-diaphragm distributor mechanism.**

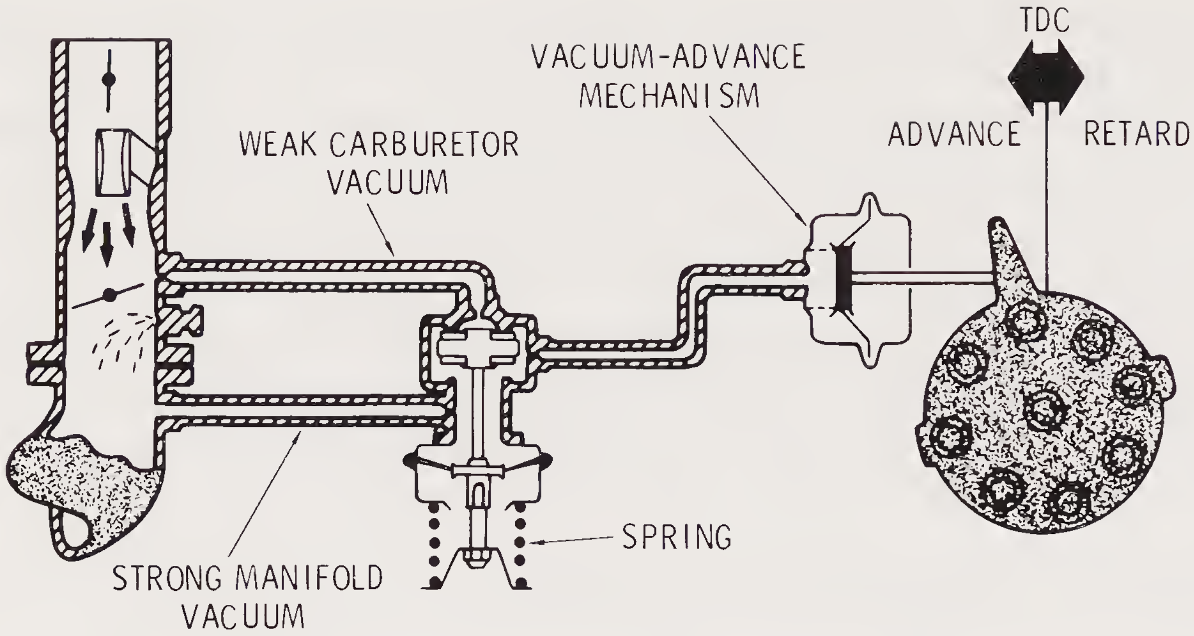



**Fig. 18-10. Spring-loaded vacuum-advance control valve.**

retarded spark during idle. See Fig. 18-11. The spring-loaded valve is subjected to both carburetor vacuum and manifold vacuum. During idle, manifold vacuum is too weak to overcome the spring; the carburetor vacuum is transmitted to the distributor and is too weak (at this time) to advance the special distributor. Also, during acceleration and cruise the manifold vacuum is too weak and carburetor vacuum acts on the mechanism, but since carburetor vacuum is now strong, the mechanism is advanced in a conventional manner. During deceleration, when manifold vacuum is high, the valve diaphragm moves its plunger to transmit this vacuum to the distributor, and the spark remains well advanced.

Instead of the spring-loaded valve, some systems use a solenoid valve. The solenoid is energized by operation of either an ambient-air or a coolant-temperature switch. At temperatures below a predetermined degree, the switch energizes the solenoid to position the valve so that carburetor vacuum is selected for spark-advance control; at higher temperatures the deenergized solenoid positions the plunger so that manifold vacuum is selected. Thus, selection of vacuum source becomes a function of the temperature rather than of the relative "strengths" of the two vacuum sources.

## Spark-Delay Valve

This valve is used in a "system" which also includes a *one-way check valve*, a *coolant-temperature sensing switch* and a *solenoid vacuum*

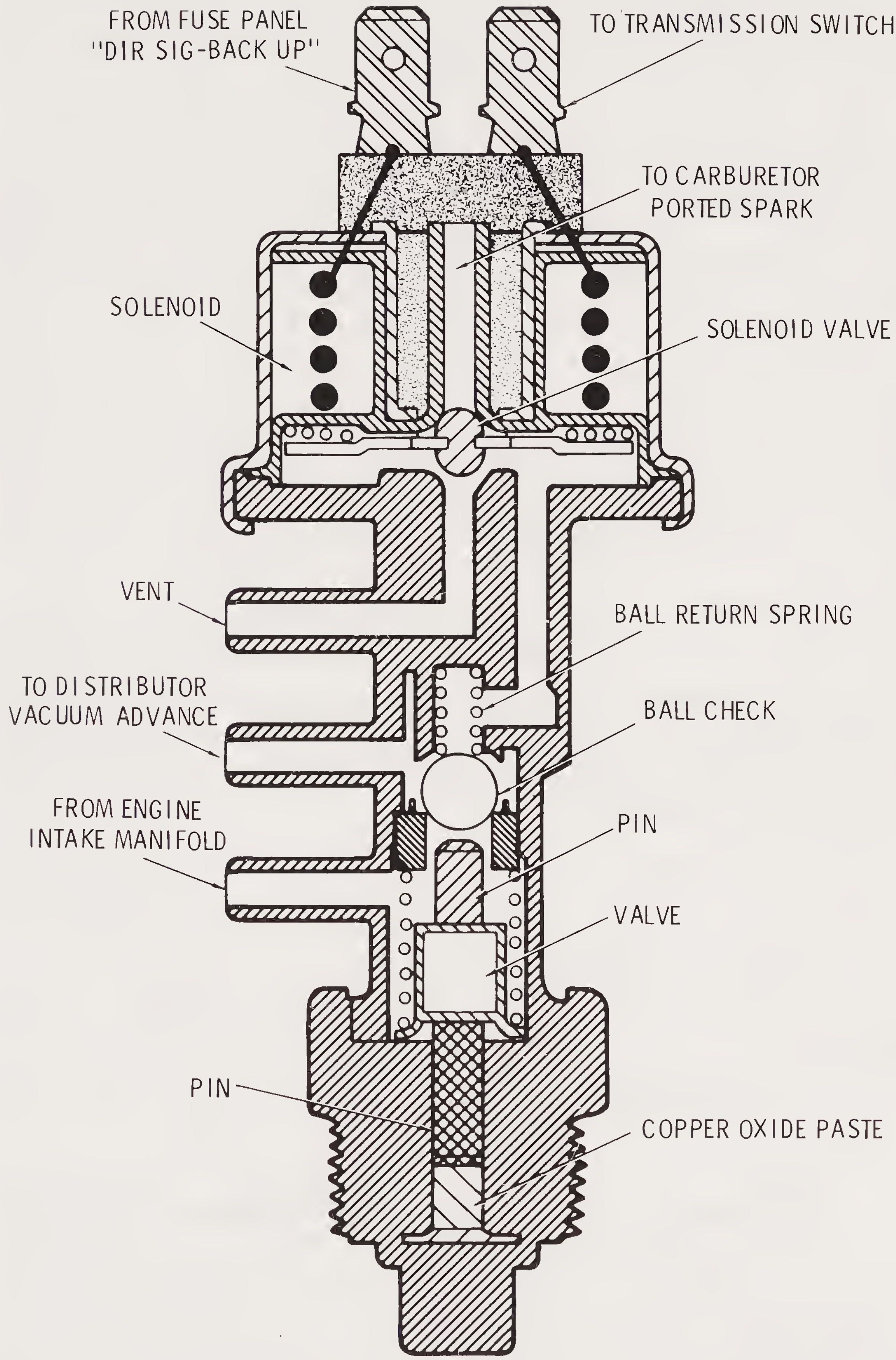



**Fig. 18-11. Solenoid-operated vacuum-advance control valve.**

*valve*. The spark-delay valve is constructed to permit free flow of air in one direction (through an integral one-way check valve), but to delay flow in the opposite direction (there is a bypass containing a sintered metal restrictor). See Fig. 18-12.

The one-way check valve is installed in the vacuum line between the carburetor and distributor so as to check the flow from the distributor to the carburetor, but to allow flow in the opposite direction. The spark-delay valve is in a bypass line around the check valve, and restricted flow through the spark-delay valve is in the direction from the distributor to the carburetor.

During acceleration, the increasing carburetor vacuum creates a lower pressure in the line between the check valve and carburetor than between the distributor and check valve—and the check valve closes to stop the distributor vacuum advance. However, this lower pressure is also applied through the solenoid vacuum valve to the spark-delay valve, which permits air to bleed through its restrictor until the pressures at both sides of the check valve are equalized and the check valve again opens. Thus, vacuum advance of the spark is delayed by the amount of time required for the air to bleed through the spark-delay valve; and this time is proportional to the rapidity of the acceleration (which determines the amount of pressure differential to be dissipated).

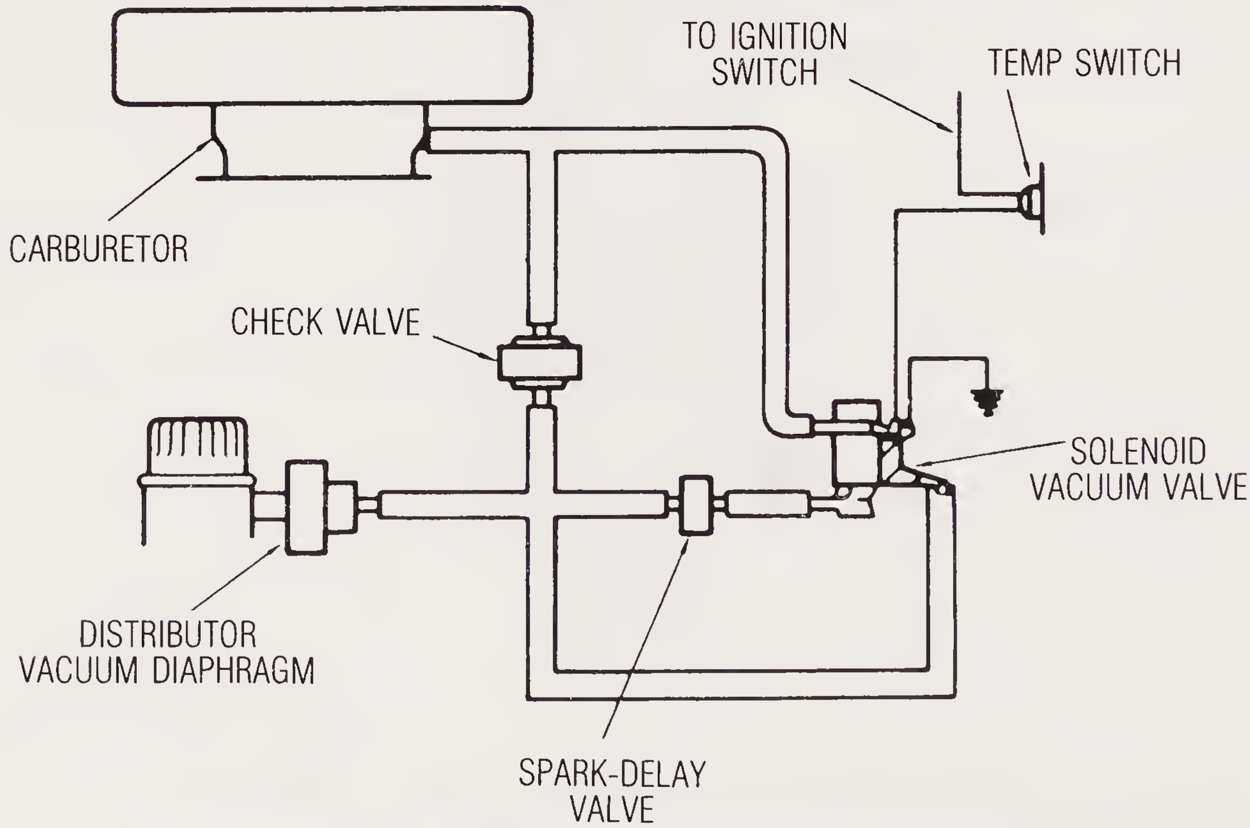



**Fig. 18-12. Typical spark-delay valve application.**

During deceleration the pressure differential across the check valve and the spark-delay valve is reversed. The check valve therefore remains open (or instantly opens, if closed). Vacuum operation of the distributor remains normal.

The solenoid vacuum valve is connected into the system so that, when open, it will bypass both the check valve and the spark-delay valve and provide an open line between the carburetor and distributor. When it is closed, airflow in the vacuum line around the check valve must pass through the spark-delay valve, as already explained. This valve is normally open; it is activated and closed only when the ignition switch is on and the temperature switch is closed. This occurs when ambient temperature is below a specified degree. Consequently, at temperatures above the design degree, the spark-delay system operates at temperatures below this design degree; the spark is advanced in a conventional manner.

## Coolant-Sensing Switch

Prolonged idling with a leaned mixture and retarded spark (as will be explained later) can overheat an engine. To avoid overheating, a thermal sensing device is installed somewhere in the engine block or head where it will react to coolant temperature. This spring-loaded, thermal-expansion device moves a check ball to open or close vacuum lines that control distributor timing. See Fig. 18-13.

It functions to cut off manifold vacuum and allow the "spark control" (explained later) to operate, unless coolant temperature exceeds a predetermined amount, at which temperature it "takes over" by allowing the manifold vacuum to advance the distributor timing, thus permitting the engine to idle at a cooler temperature.

## Electronic and Computer-Controlled Timing

Either an electronic ignition distributor or a modified conventional distributor may be used. The modified distributor has two separate spark-timing mechanisms offset from each other by the desired spark-advance increment. Thus, one mechanism determines initial timing; the other, advanced timing—and an electronic control selects the one to be used in accordance with engine operating conditions.

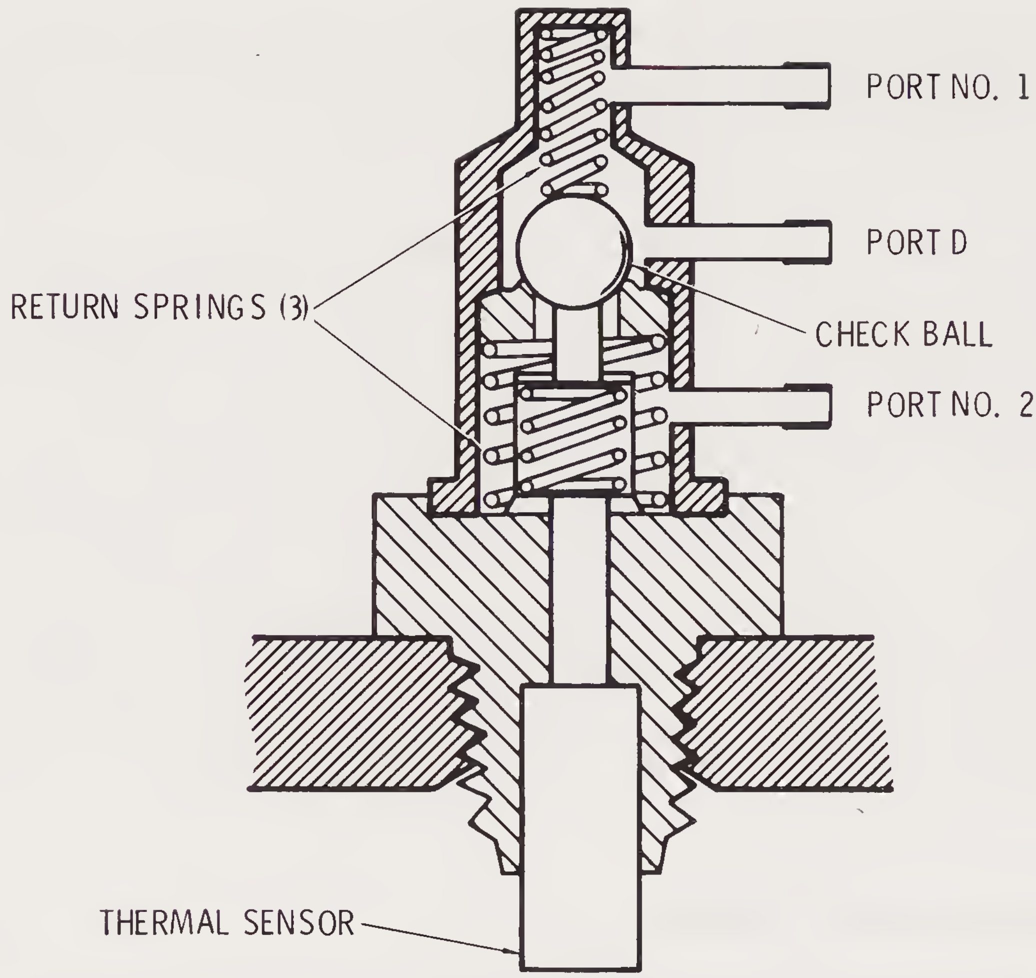



**Fig. 18-13. Typical coolant-sensing (thermo-vacuum) switch.**

Both systems employ a number of data feed-in sensors. Typically, these "report" engine condition (cold or hot) at starting, engine rpm (or transmission gear), intake manifold vacuum, throttle position, and carburetor air temperature and/or coolant temperature. Sensors generally are nonserviceable units that must be replaced if malfunctioning.

## UNBURNED EXHAUST CONTROLS

Two different systems are used to reburn the unburned portions of exhaust in the exhaust manifold. One is an *air-injection system* that uses an air pump to feed fresh air (and, therefore, oxygen) into the manifold. The other, a *pulse air-injection reactor system*, uses exhaust pressure pulsations to accomplish the same purpose. See Fig. 18-14.

### Air-Injection System

A typical system contains an *air pump* (driven by the engine fan belt), a *diverter valve*, a *check valve(s)* (one valve is used, as illus-

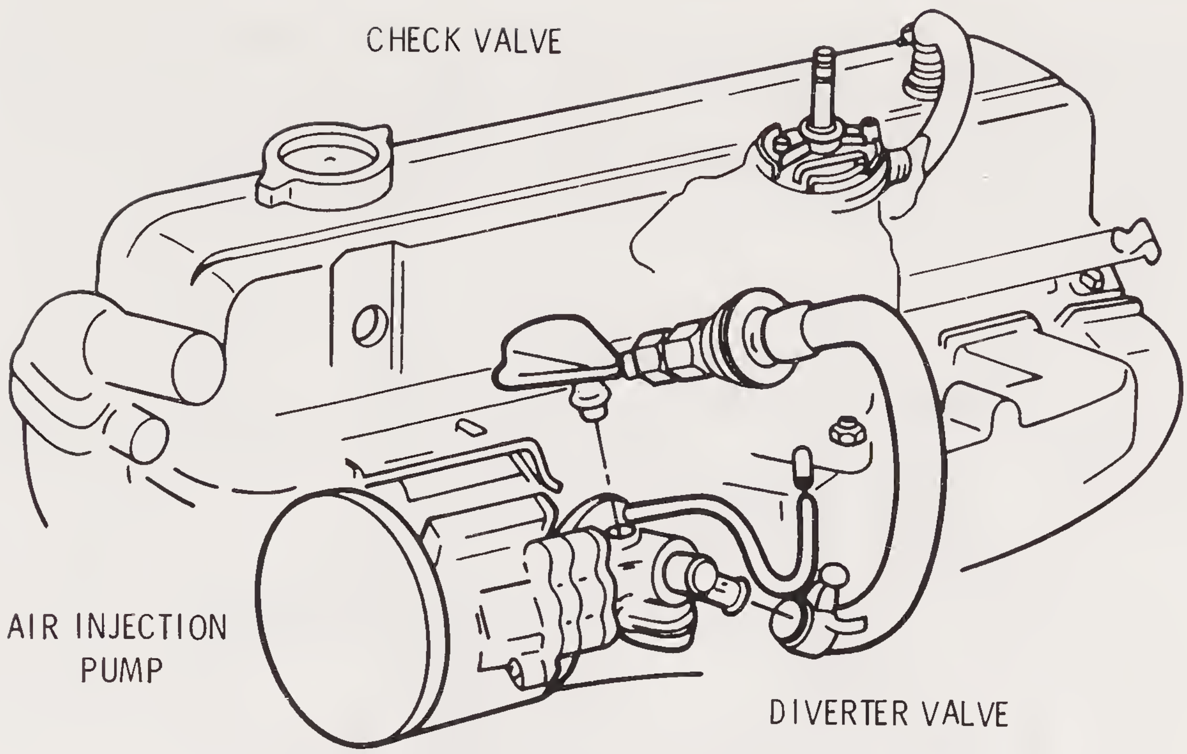



**Fig. 18-14. Typical air injector system.**

trated, for an in-line engine; two valves, on each side, for a V-8 engine), and (not shown) one (or two) *air manifold(s)* with a separate *injection tube* to the exhaust manifold(s) at each of the exhaust port locations. The system pumps filtered under-hood air into the exhaust manifold at all the cylinders' exhaust-port locations simultaneously. Excess air is dumped to the atmosphere through a pressure relief valve, either in the air pump or the diverter.

Fig. 18-15 is a rotary-type pump having a centrifugal air filter and may be fitted with an integral pressure-relief valve. If this valve is not in the air pump, there must be one located in the diverter, since the system has to have means of purging excess airflow created by the pump. Airflow becomes excessive whenever the engine is operating at high speed and during deceleration when there is a sharp increase in intake manifold pressure. During engine overrun, the entire air supply is dumped by the relief valve.

## Diverter (Air Bypass) Valve

The diverter valve operates by vacuum from the intake manifold, a spring-loaded diaphragm-actuated valve that is normally open to allow air to flow through to the system. Any sudden increase in manifold vacuum causes the diaphragm to collapse against the spring, partially or wholly closing the valve. Whenever the valve is

closed or there is an excess of air entering the inlet, air pressure opens the spring-loaded relief valve to allow air to escape from the system (or, as previously mentioned, the relief valve may be in the air pump, instead). See Fig. 18-16.

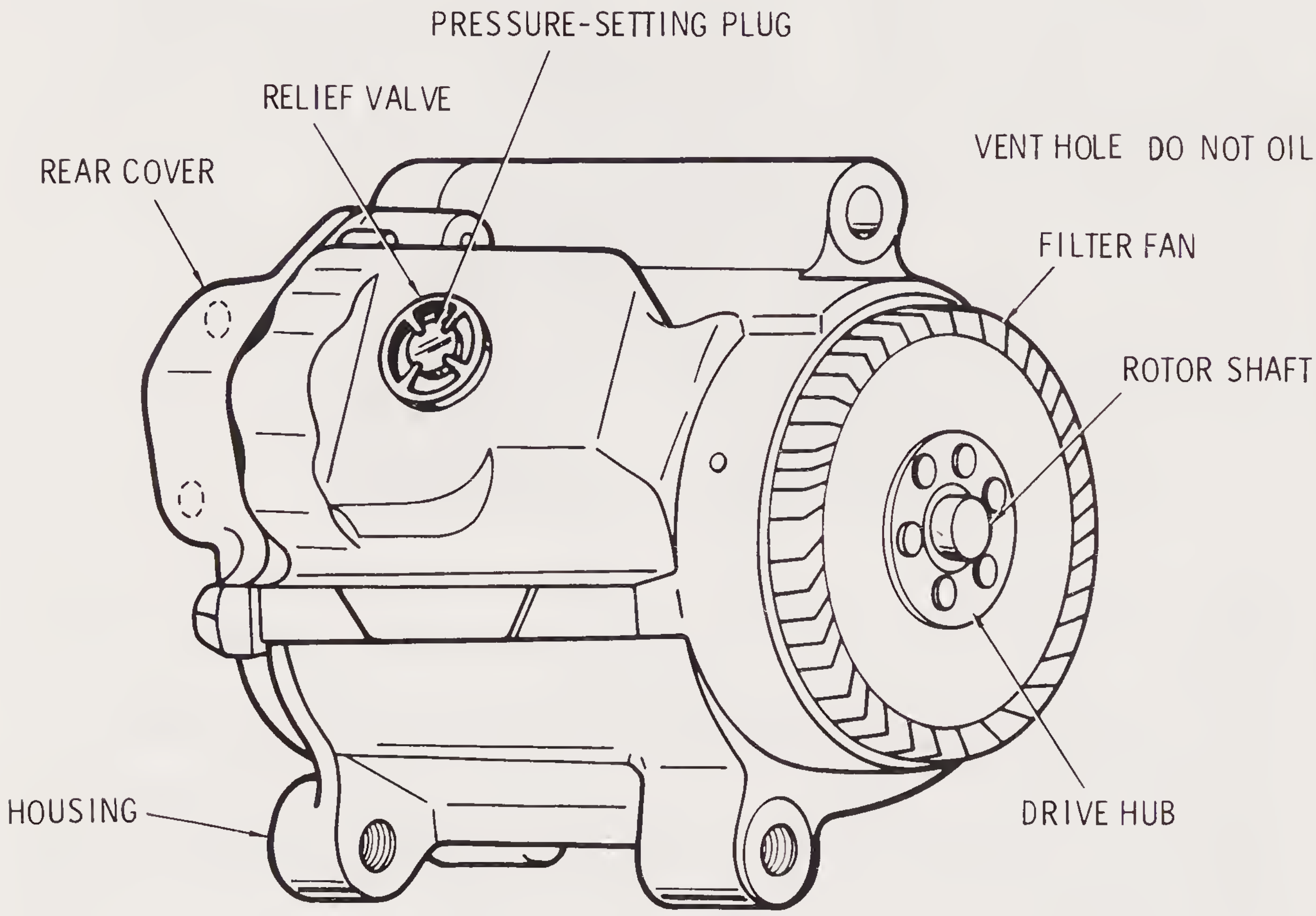



**Fig. 18-15. Air pump with integral relief valve.**

A simple ball-type check valve is used to prevent backflow of exhaust gasses through the system. Some systems also use a *mixture-control* (or *backfire bypass*) *valve*; other systems incorporate a *vacuum differential valve* together with (or without) a solenoid valve to regulate the diverter operation.

On systems used with new high-efficiency exhaust catalytic converters, the diverter is used to direct airflow. During normal warm-engine operation, the diverter valve pumps air directly into the catalytic converter. During cold-engine warm-up, the diverter valve is used to reroute air pump output to the exhaust manifold. Pumping fresh air into the exhaust manifold serves to dilute the overly rich mixture produced by the choke and helps cool the converter, protecting it from overheating.

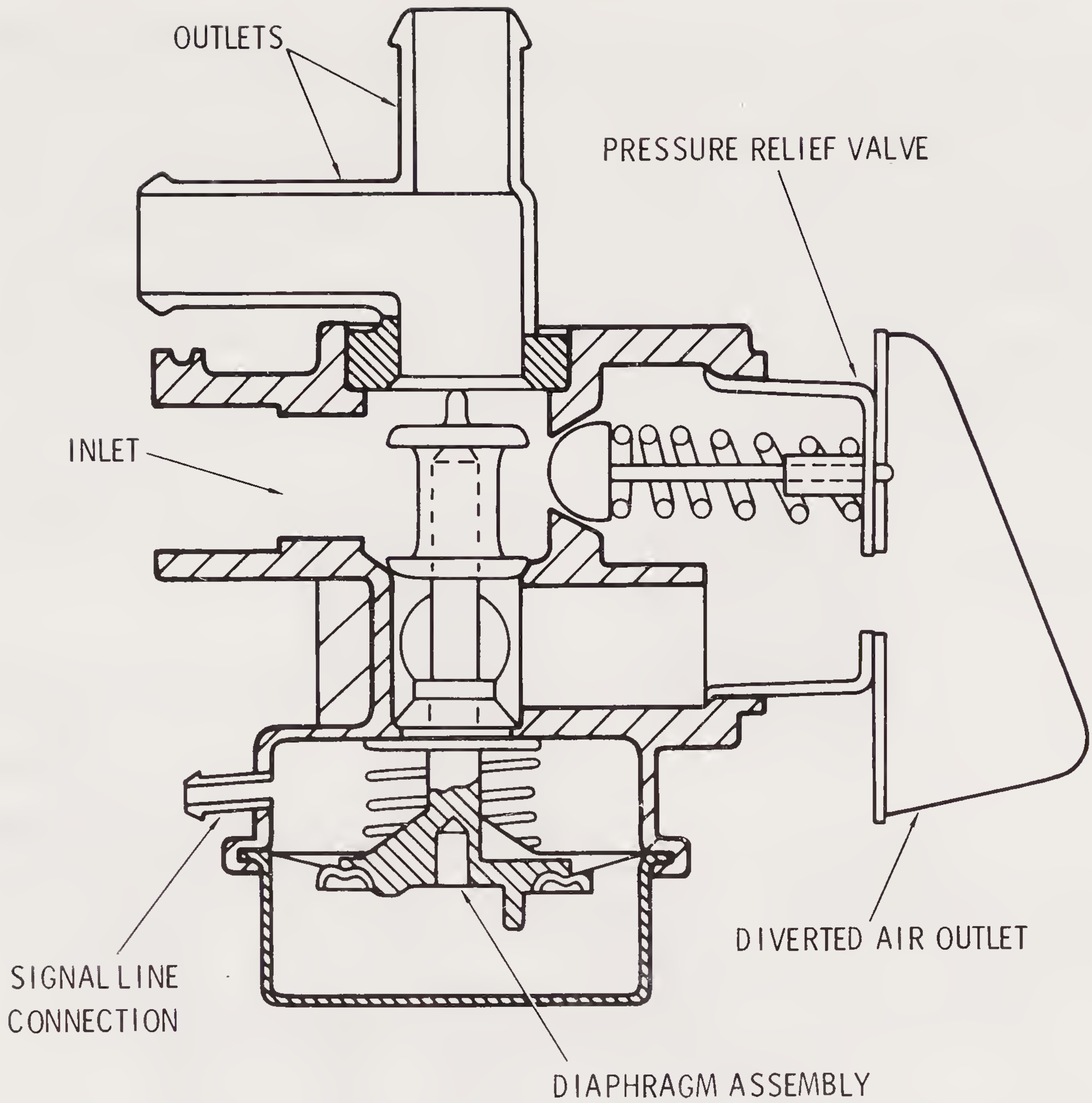



**Fig. 18-16. Diverter with integral relief valve.**

## Backfire Bypass Valve

Similar to the diverter valve, and also operated by manifold vacuum, this normally closed valve is opened by any sharp increase of manifold vacuum (as during deceleration). When open, it supplies fresh air to the intake manifold to offset the mixture enrichment—resulting from the high manifold vacuum—thus preventing backfire through the air-injection system. See Fig. 18-17.

## Vacuum Differential Valve

This diaphragm-actuated valve is installed in the vacuum line to the diverter valve and is operated by the pressure differential at the two sides of its diaphragm. A small orifice between the two chambers keeps the pressures equalized—and the valve closed—except when

the manifold vacuum is increasing (as during acceleration or deceleration), at which time the sudden excess of pressure in one chamber opens the valve. Opening of the valve admits air into the vacuum line, thus "dumping" the vacuum and closing the diverter valve (which in this system is normally closed). Shortly after opening, air bleed through the orifice will reequalize the pressures and allow the valve to close again. Air injection by the system is thus wholly or partially interrupted in accordance with manifold vacuum.

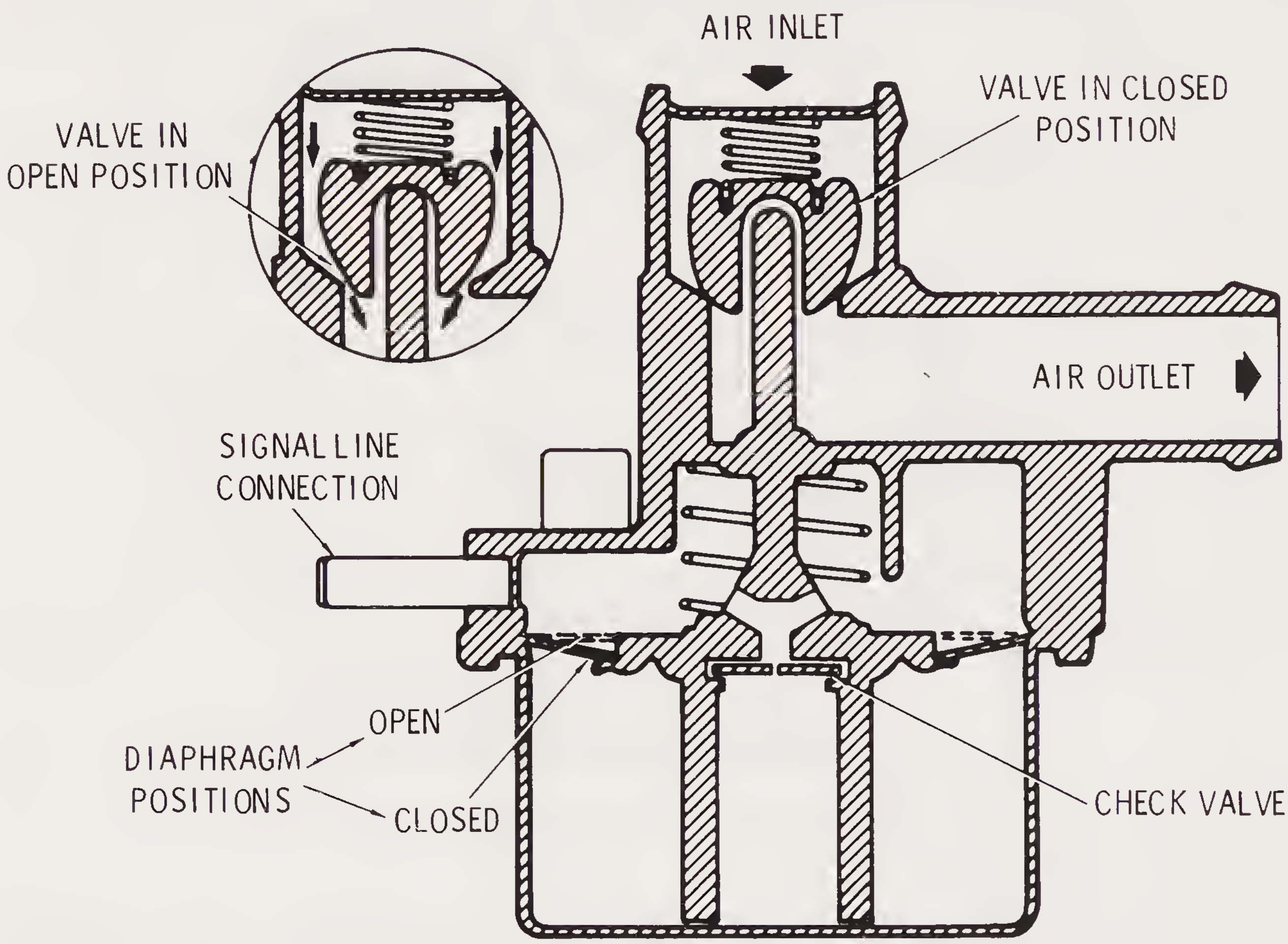



**Fig. 18-17. Backfire bypass valve.**

## Solenoid Valves

When used, this type of valve is installed in the vacuum line ahead of the vacuum differential valve, and also serves to open or close the vacuum line. The solenoid is electrically operated by a circuit containing a temperature sensor (switch). This sensor is located in the air cleaner (in some models, there is also one in the floor pan), and the system is designed to shut off the diverter valve (stop air injection) when the engine is cold and (some models) when it becomes overheated.

## Pulse Air-Injection Reactor System

This system contains one *check valve* for each cylinder and one *air shut-off valve* to serve the whole system, together with necessary air and vacuum lines. In operation, the system "sucks" air from the air cleaner into the exhaust manifold at each cylinder's exhaust port, doing so for each cylinder during the piston exhaust stroke. However, the system operates only when the engine is idling or cruising; it will shut off at high engine rpm and whenever intake manifold vacuum suddenly increases (as during rapid deceleration). See Fig. 18-18.

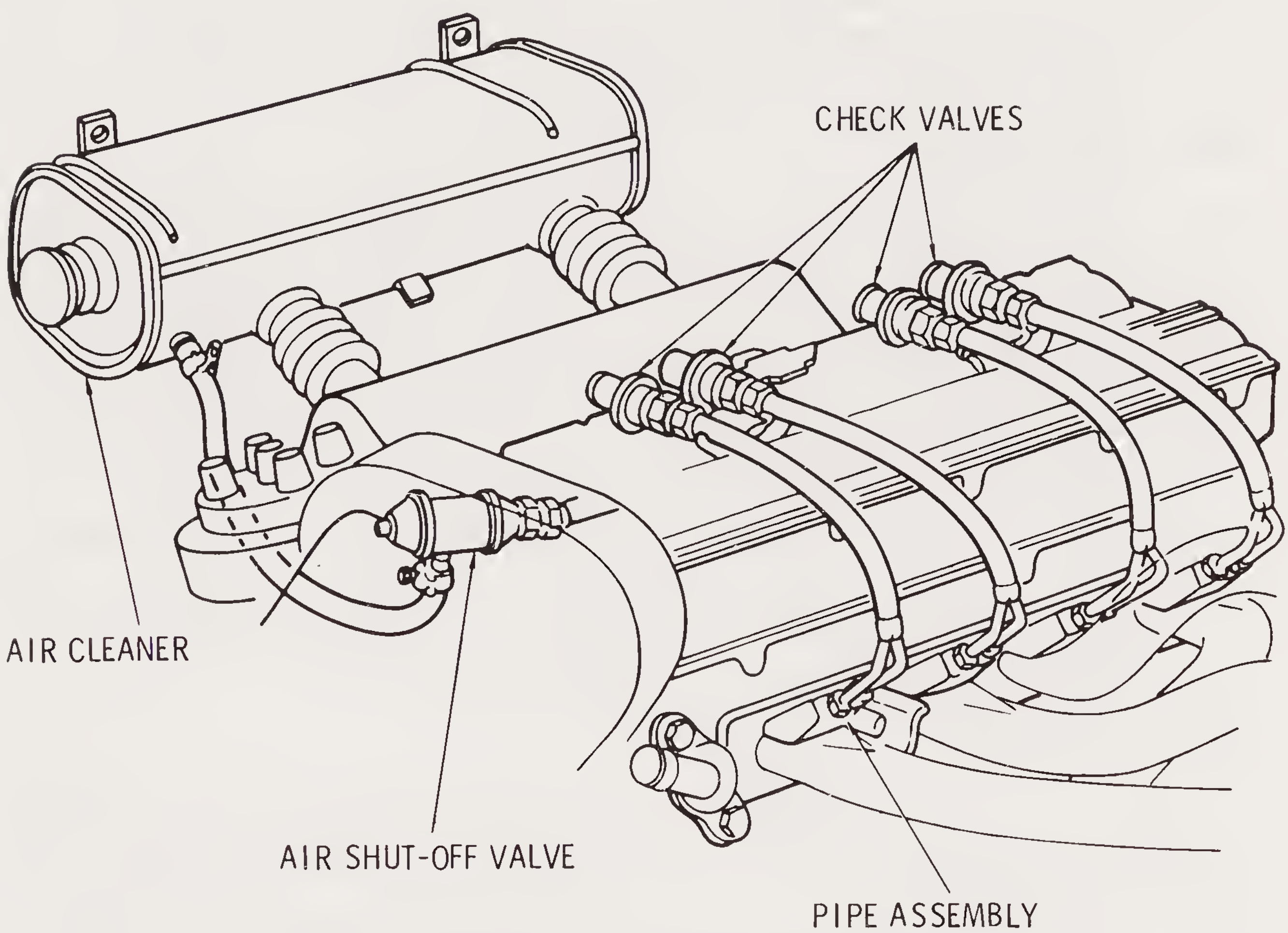



**Fig. 18-18. Pulse air-injection reactor system.**

## Check Valves

These are one-way, disc-type valves installed in the lines so that each will open when its associated cylinder's exhaust valve opens (thus increasing manifold vacuum at this point), and close when the exhaust valve closes. Due to inertia, however, valve opening is

reduced as the engine speeds up (diminishing the flow of injected air), and it fails to open (shutting off the air) when engine rpm reaches the valve design limit.

## Air Shut-Off Valve

This is a spring-loaded diaphragm valve operated by intake manifold vacuum and installed so as to shut off the air supply to all the check valves whenever intake manifold vacuum exceeds a predetermined value. The purpose is to prevent backfire, which could be caused by air induction into the exhaust during deceleration when the mixture is overly enriched.

## $NO_x$ Controls

Now used on all engines, an *exhaust-gas recirculation system (EGR)* reduces the formation of oxides of nitrogen by metering sufficient exhaust gas into the intake manifold to reduce the peak temperature of the burning mixture within the combustion chambers. Some engines also have an added spark-advance control which contributes to the reduction of $NO_x$ by preventing vacuum spark advance at engine speeds below and at temperatures above predetermined amounts.

## EGR Systems

A typical system, as illustrated, contains an *EGR valve* and a *coolant-temperature switch*, and may also include two vacuum signal modulators (not shown)—one for low temperature, the other for high—and connecting hoses. Other units included in some systems are an *exhaust back-pressure transducer*, *delay timer*, and a *high-speed modulator*. Basically, a system introduces exhaust gases into the intake manifold at engine speeds other than idle (when the addition of exhaust gases would result in rough engine operation). This is accomplished by the EGR valve; all the other units are used, in one way or another, to modulate the flow of exhaust gases through the EGR valve to compensate for periods of deceleration or engine

overload—or to close down the EGR system at temperatures below or above specified degrees. See Fig. 18-19.

Except in certain modulated systems, the EGR valve is operated by vacuum taken from the carburetor EGR port (below the throttle); exhaust gases are taken from the exhaust crossover passage or near the bottom of the riser area, and are ported to the intake manifold floor below the carburetor.

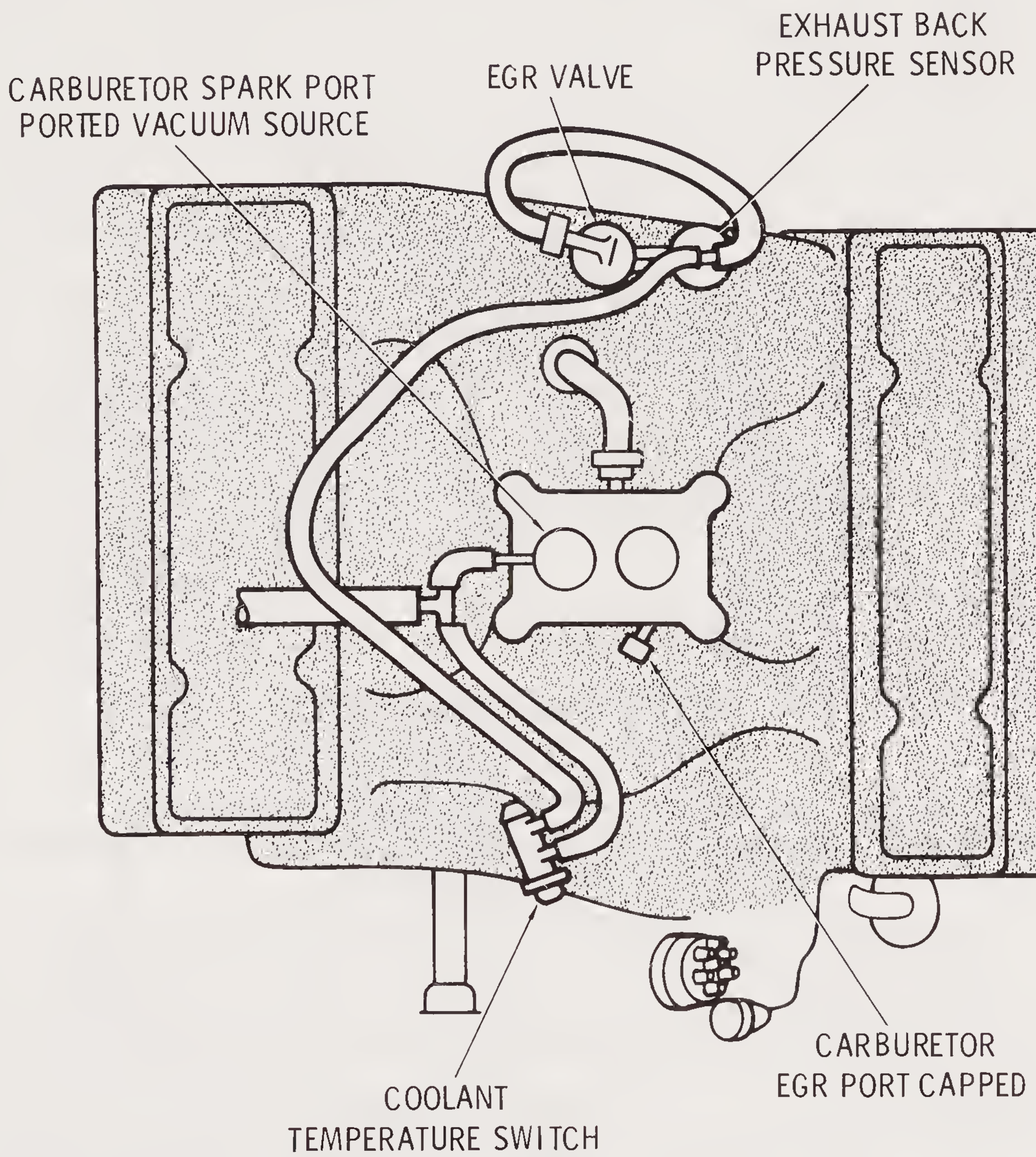



**Fig. 18-19. Typical EGR stystem with a back-pressure sensor.**

## EGR Valves

Two basic types are illustrated in Fig. 18-20. Both types are mounted on the intake manifold, at top or side. The single-diaphragm valve is operated by vacuum from the EGR port to start opening at a

specified vacuum measure (in./Hg.) and to become—and remain—fully open at a higher specified measure. This is a spring-loaded, diaphragm-actuated valve that is normally closed at idle (when spring pressure exceeds the "start-to-open" vacuum suction), partially open at slow speeds and during acceleration (when vacuum suction is low), and fully open during cruising and deceleration. To offset the higher formation of $NO_x$ during slow-speed operation and acceleration, by increasing exhaust gas recirculation at these times, systems using this type of valve may include a back-pressure switch or transducer valve.

When the more flexible (in operation) dual-diaphragm valve is used, the EGR vacuum is taken from the carburetor spark port (above the throttle). An additional vacuum, taken from the intake manifold, is transmitted to the area between the two diaphragms (which are mechanically joined to move together). The upper diaphragm has a larger piston than the lower diaphragm. Therefore, suction created by manifold vacuum helps the spring to keep the valve closed or partially opened. It follows that during cruising, deceleration or engine overload, when manifold vacuum is high, the valve is only partially open, but at low speeds and during acceleration, when manifold vacuum is low, the valve becomes fully opened to recirculate a maximum amount of exhaust gases.

## Exhaust Back-Pressure Transducer (Switch or Valve)

This unit serves to regulate EGR operation by permitting exhaust gas recirculation or stopping it, according to the back pressure in the exhaust manifold. The single-diaphragm EGR valve that is used takes its vacuum from the carburetor spark port (instead of the EGR port), and the transducer is connected into the vacuum line ahead of the EGR valve. Valve operation either opens a vent (in the valve) to dissipate the vacuum and keep the EGR valve closed, or closes the vent and allows normal operation of the EGR valve. See Fig. 18-21.

The spring-loaded, diaphragm-actuated valve normally holds the vent open. A probe (tube) connects the valve with the exhaust manifold crossover. Whenever exhaust back pressure is high (during acceleration and some cruise conditions), the diaphragm is moved

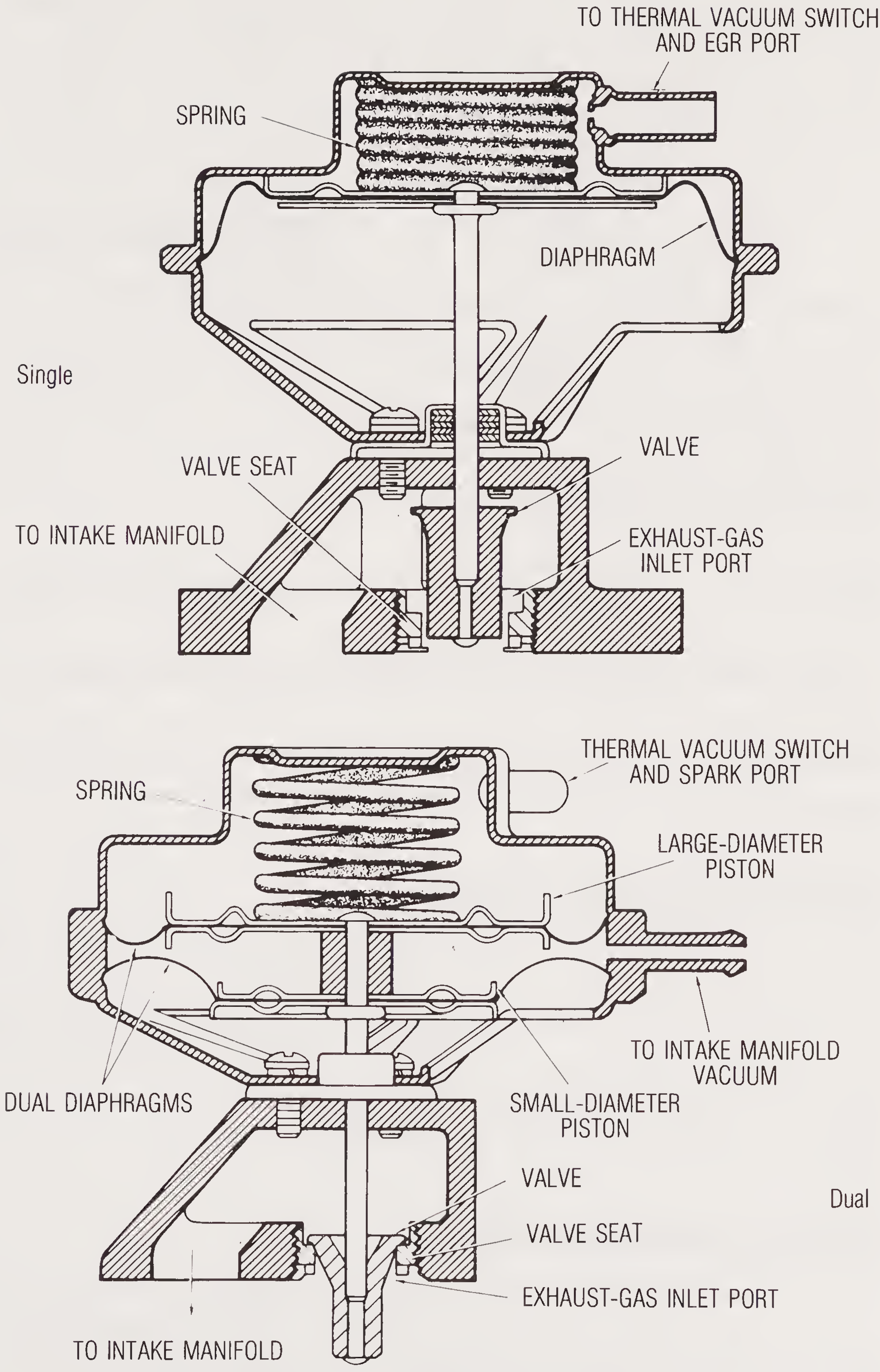



**Fig. 18-20. Single- and dual-diaphragm EGR valve.**

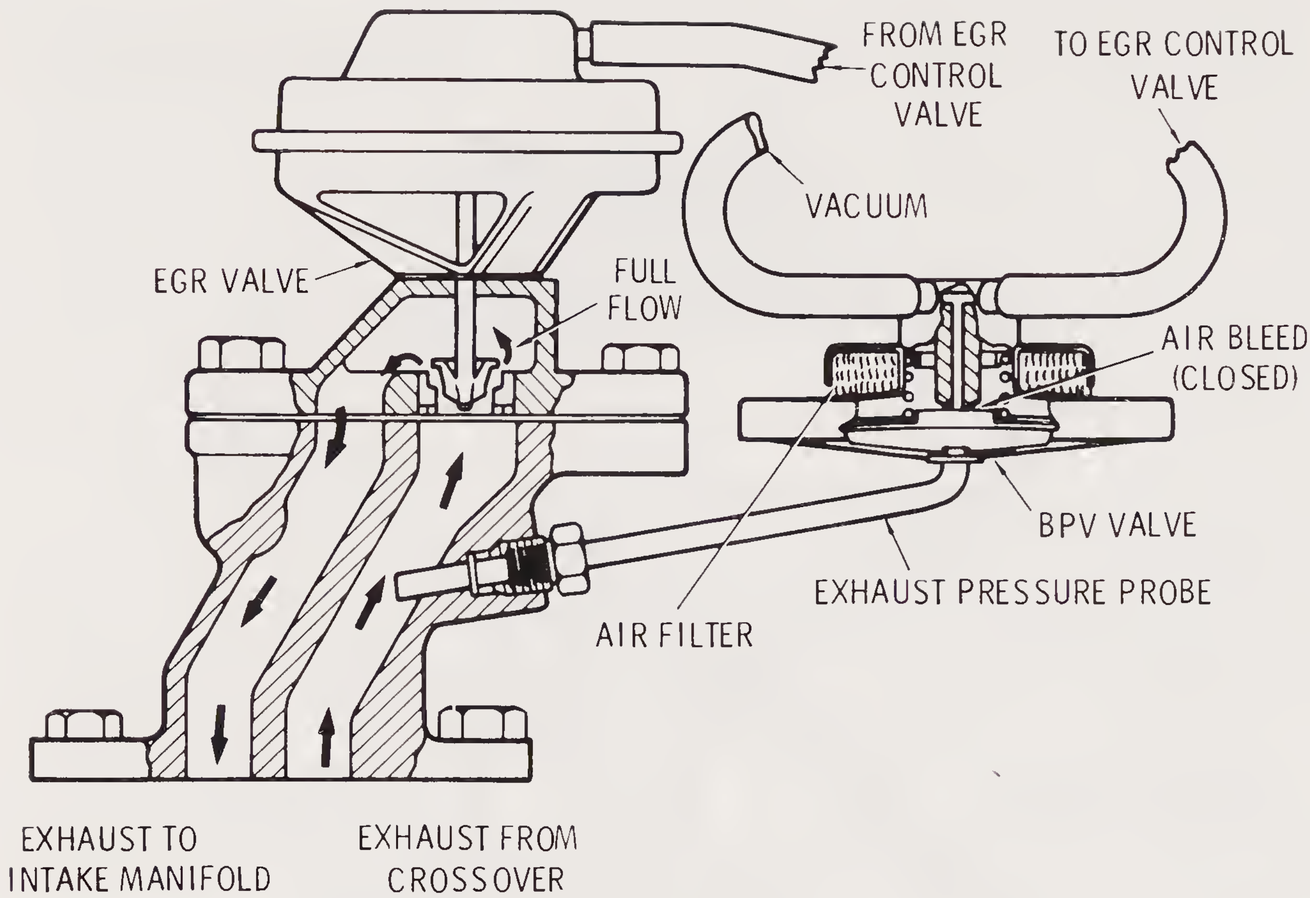



**Fig. 18-21. Typical exhaust back-pressure transducer installation.**

to close the vent; at other times the vent remains open. The valve is precisely calibrated for its particular engine application.

## Coolant-Temperature Switch

This is the same as the coolant-sensing switch (Fig. 18-13). Mounted where it can sense engine-coolant temperature and in the vacuum line ahead of the EGR valve, the switch serves to close off the EGR-valve vacuum whenever temperature is below a predetermined degree. In short, it prohibits exhaust gas recirculation when the engine is cold. Most systems include such a switch.

## Vacuum Signal Modulators

These are electrically operated ambient-temperature switches installed, when used, in the vacuum line ahead of the coolant temperature switch. Operation is such as to partially close the vacuum

line and weaken the signal to the EGR valve whenever either switch is activated. The low-temperature switch is usually mounted near the engine radiator and is activated at temperatures below a predetermined degree. The high-temperature switch is mounted at the rear of the engine compartment and is activated at temperatures above a predetermined degree.

## Delay Timer

This is an electrically operated timer connected with a solenoid valve in the EGR vacuum line ahead of the EGR valve. Energized when the ignition switch is turned on, the timer circuit holds the solenoid valve closed for a predetermined number of seconds (after engine starting) to prevent exhaust gas recirculation. Afterwards, the solenoid valve opens to allow normal EGR system operation.

## High-Speed Modulator

This is a subsystem sometimes used to cut off exhaust gas recirculation at high vehicle speeds to improve performance. The system includes a normally open solenoid valve in the vacuum line ahead of the EGR valve, together with an electrical system to energize (and close) the solenoid valve. Electrical components include a speed sensor, driven by the speedometer cable, that produces a voltage proportional to the vehicle speed, together with an electronic module that monitors this voltage and switches on the solenoid circuit according to design plan.

## $NO_x$ Spark-Advance Controls

$NO_x$ emissions are increased by an advanced spark during periods when the engine is already warmed up and the gears are being upshifted or the vehicle is traveling slowly (as on a crowded city street). During such periods, it is desirable to prevent vacuum spark advance. Some manufacturers therefore install additional controls to prevent spark advance except under cruising conditions. There are two types.

The manual transmission control is a solenoid vacuum valve

operated by a switch mounted on the transmission housing. The normally open valve is in the vacuum line to the distributor, and the switch is in "off" position whenever the transmission is in high gear. Shifting to any other gear turns the switch to "on," activates the solenoid, and causes the valve to close the vacuum line and prevent vacuum spark advance.

The automatic-transmission control is also a solenoid vacuum valve that functions in a similar manner, but this valve is normally closed and is operated by a speed-sensing switch similar to the one previously described (see "High-Speed Modulator," above). At speeds below the design mph the valve remains closed to prevent vacuum spark advance, but at higher speeds the switch activates the solenoid to open the valve and permit conventional spark advance.

Both control systems include an overriding ambient-temperature thermal switch that serves to prevent closing of the solenoid valve when the temperature is below a design degree. Hence, during cold-engine operations the spark advance is conventional.

## CATALYTIC CONVERTERS

The converter is an integral, nonserviceable unit installed in the exhaust pipe, usually between the exhaust manifold and the muffler, although some are built into the exhaust manifold itself. Converters are made in different shapes and sizes to suit their applications, but all operate on the same basic principle. A basic oxidation catalyst, consisting of noble metals (platinum, etc.), is used to combine HC and CO pollutants in the exhaust gases with oxygen to form, instead, harmless $H_2O$ (water) and $CO_2$ (carbon dioxide). This catalyst is made permanent by being coated on an inert material formed either into pellets or into a single honeycombed shape, and does not become chemically changed or dissipated by the process. Consequently, a converter unit will last indefinitely if not abused. See Fig. 18-22.

A converter, however, cannot be used with leaded fuel; the lead will coat and destroy the catalyst. If enough lead accumulates, it may begin to block the exhaust system and cause poor running and permanent engine damage. For this reason, vehicles so equipped are fitted with gas-tank filler, tubes too small in diameter

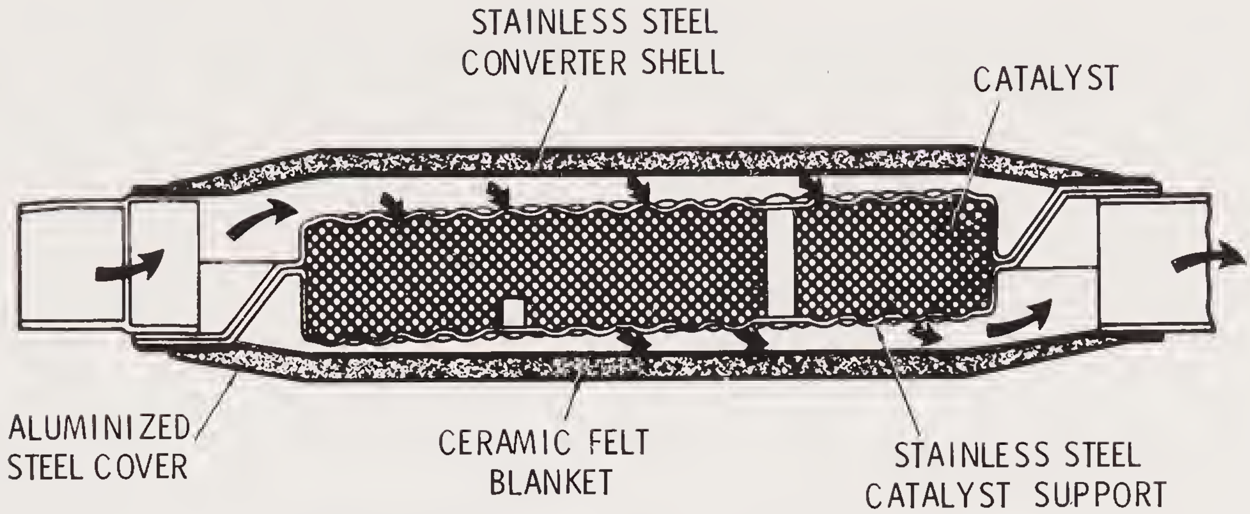



**Fig. 18-22. Typical catalytic converter.**

to admit conventional gas-pump nozzles; a smaller nozzle, now universally adapted for unleaded-fuel pumping, must be used.

A converter creates considerable chemically generated heat. For this reason, most vehicles so equipped are also fitted with *heat shields*. These heat deflectors serve to protect the vehicle flooring and chassis components.

Some cars also have a *catalyst protection system* designed to prevent overheating of the converter during high-speed deceleration (when HC and CO pollutants are at maximum). The system contains an electronic engine-speed switch, or control unit, and a solenoid mounted so as to regulate throttle position when energized. At engine speeds above 2000 rpm the solenoid holds the throttle slightly open (a fast idle) so that during deceleration speed must drop below 2000 rpm before the throttle is allowed to close to normal idle position.

CHAPTER 19

# Friction Clutches

Although friction clutches as such do not constitute a part of a gas engine, they are nevertheless used to transfer power between the engine and its load in numerous instances. This is particularly true in automotive applications, and it is because of this fact that a brief explanation of the construction and operation has been included.

By definition, a clutch is a mechanical device for connecting or disconnecting two pieces of shafting in the same line, or a shaft and a wheel, so that they revolve together or are free.

The function of a clutch, therefore, is to connect the engine to the mechanism of the driven machinery or gear transmission system. Since the internal combustion engine does not develop a high starting torque, it must be disconnected from the transmission system and allowed to operate without load until it develops enough torque to overcome the inertia of the load when starting.

# CLUTCH PRINCIPLES

The transmission of power through the clutch is accomplished by bringing one or more rotating drive members secured to the crankshaft into gradual contact with one or more driven members secured to the unit being driven. These members are either stationary or rotating at different speeds. Contact is established and maintained by strong spring pressure controlled manually through the clutch pedal and suitable linkage. Thus, as spring pressure increases, the friction increases; therefore, when the pressure is light, the comparatively small amount of friction between the members permits a large amount of slippage.

As the spring pressure increases, less slippage occurs until, when the full spring pressure is applied, the speeds of the drive and driven members are the same.

## Clutch Elements

In any clutch construction there are two principal elements:

1. A drive member.
2. A driven member.

The *drive member* is attached to the engine and turns with it, while the *driven member* is attached to the transmission and operates in a similar manner. The operating members include the spring or springs and the linkage required to apply and release the pressure which holds the drive and driven members in contact with each other.

The drive members of a clutch usually consist of two cast-iron plates or flat surfaces machined and ground to a smooth finish. Cast iron is desirable because it contains enough graphite to provide some lubrication when the drive member is slipping during engagement. One of these surfaces is usually the rear face of the engine flywheel, and the other is a comparatively heavy flat ring with one side machined and surfaced. This part is known as the *pressure plate* and is fitted into a steel cover, which also contains some of the operating members and is bolted to the flywheel.

The driven member is a disk with a splined hub that is free to slide lengthwise along the splines of the clutch shaft, but which

drives the shaft through the same splines. The clutch disk is usually made of spring steel in the shape of a single flat disk of a number of flat segments. Suitable frictional facings are attached to each side of the disk by means of copper rivets.

These facings must be heat-resistant since friction produces heat. The most commonly used facings are made of cotton and asbestos fibers woven or molded together and impregnated with resins or similar binding agents.

## Clutch Operation

The operation of an elementary clutch such as that shown in Fig. 19-1, is essentially as follows: The drive member consists of a plate **A**, attached to or forming a part of the flywheel. The driven member consists of a friction plate **B**, attached to a sleeve that engages with a splined section of the transmission shaft so that, while free to slide along the shaft, it must always turn with it.

The driven plate is normally held against the drive plate by a spring, unless released or placed in the disengaged position by pressure on the clutch pedal. Movement of the clutch pedal is transmitted to the friction plate through a yoke and collar.

*In operation*, when the clutch is engaged or *let in*, the engine shaft is connected frictionally to the transmission shaft, and if the transmission gear is in mesh, the entire drive is connected.

When the clutch is disengaged, that is, in the position shown in Fig. 19-1, there is no connection between the engine and the transmission and the engine is free to turn without movement of the transmission shaft.

## Heavy-Duty Clutches

In the elementary clutch arrangement shown in Fig. 19-1, the driven plate makes frictional contact on only one side. Evidently, by providing another drive plate with construction such that the two drive plates can engage the driven plate in frictional contact, the capacity of the clutch is greatly increased. Such arrangement should be called a three-plate clutch, but it is known as a single-plate clutch. It should also be noted that multiple-plate clutches are referred to by the number of driven, or friction, plates.

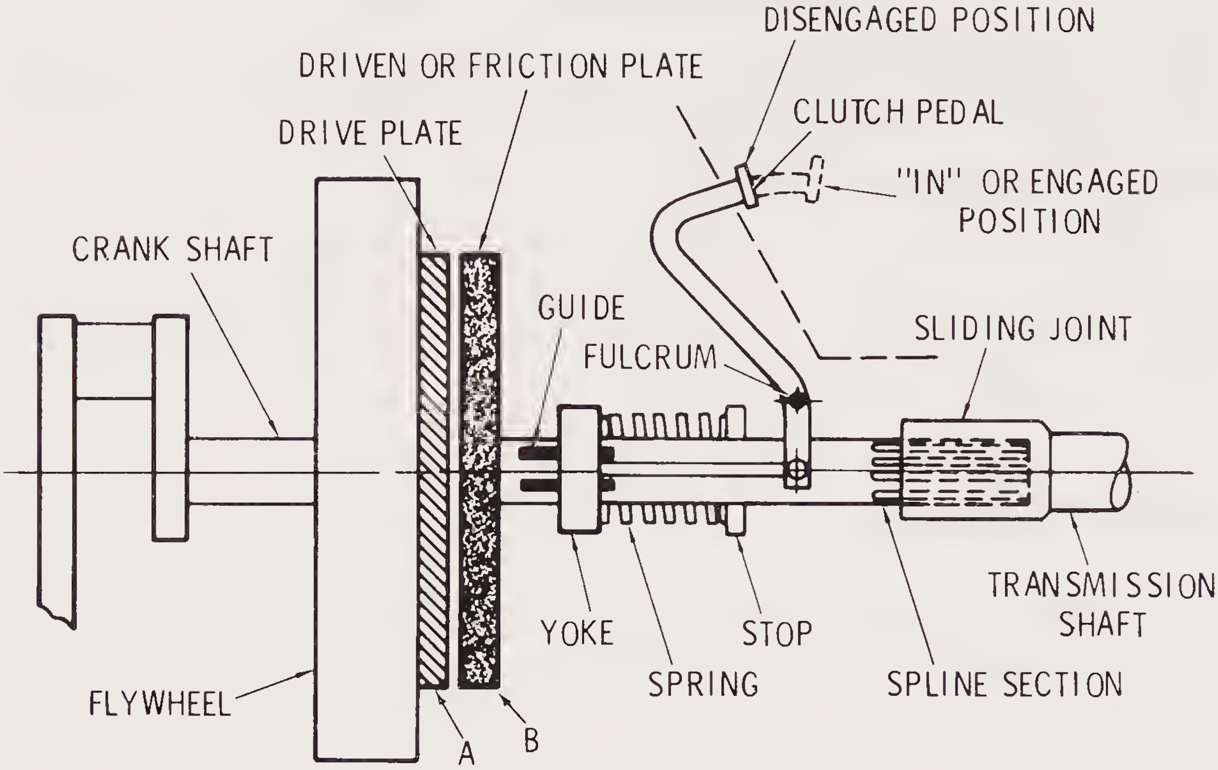



**Fig. 19-1. Elementary plate clutch system.**

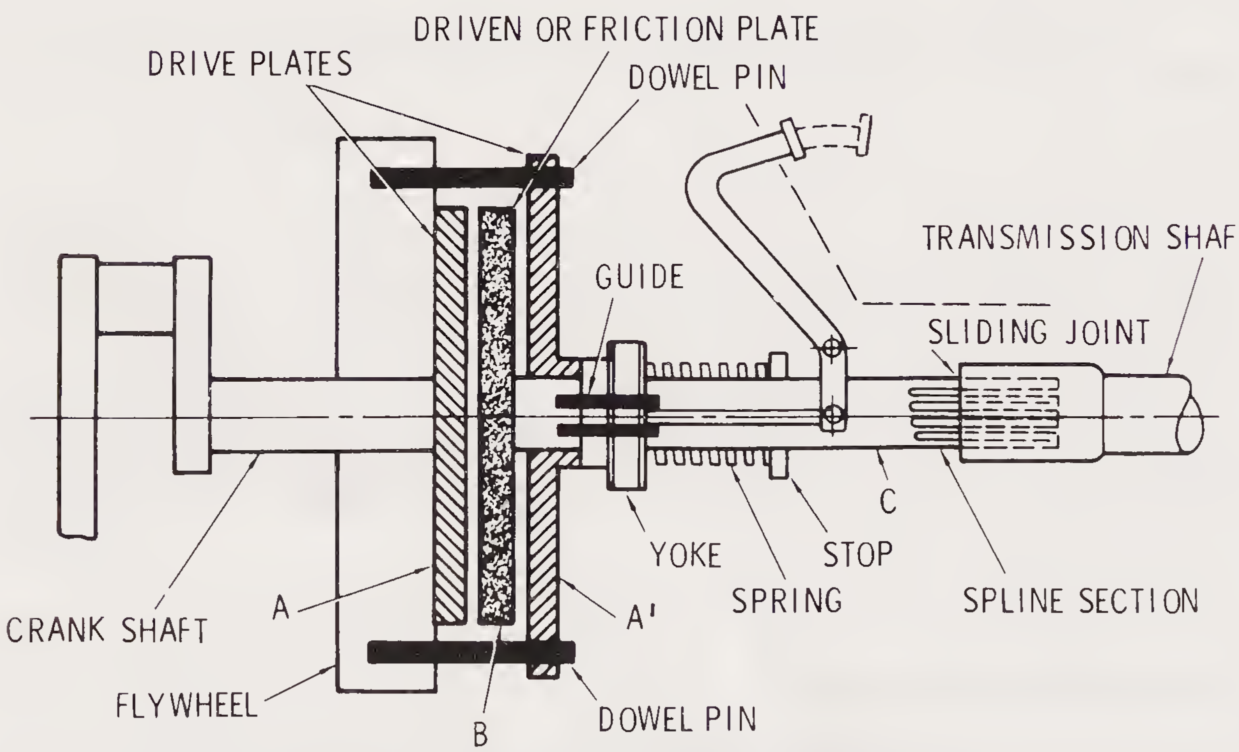



**Fig. 19-2. Elementary one-plate clutch.**

In the elementary so-called one-plate clutch, shown in Fig. 19-2, the driven friction plate **B** is attached to the shaft **C**, which has a splined section as shown. The latter meshes into a splined sleeve on the end of the transmission shaft to provide a sliding joint and positive engagement between shaft **C** and the transmission shaft.

The dowel pins on the flywheel provide a similar sliding joint for the drive plate **A′**, and also forces it to turn with the flywheel.

*In operation*, releasing the clutch pedal brings drive plate **A′** into contact with plate **B**, and pushes it over until it contacts with drive plate **A**. The pressure due to the spring holds the three plates in firm frictional contact.

For extra-heavy-duty service, so-called two-plate clutches are used. These consist of two driven, or friction, plates and three drive plates. The term *multiple-plate clutches* should not be confused with multiple-disc clutches.

## Driven, or Friction, Plate

This part of the clutch is sometimes called a disc. It is made in various ways, a typical construction consisting essentially of a thin metal disc to which is attached friction lining or facing. At the center is a hub having internal teeth which mesh with spline teeth on the transmission shaft. The essentials are shown in Fig. 19-3. Note the internal teeth on the hub, which engage the external teeth of the transmission shaft, thus providing the sliding and engaging joint.

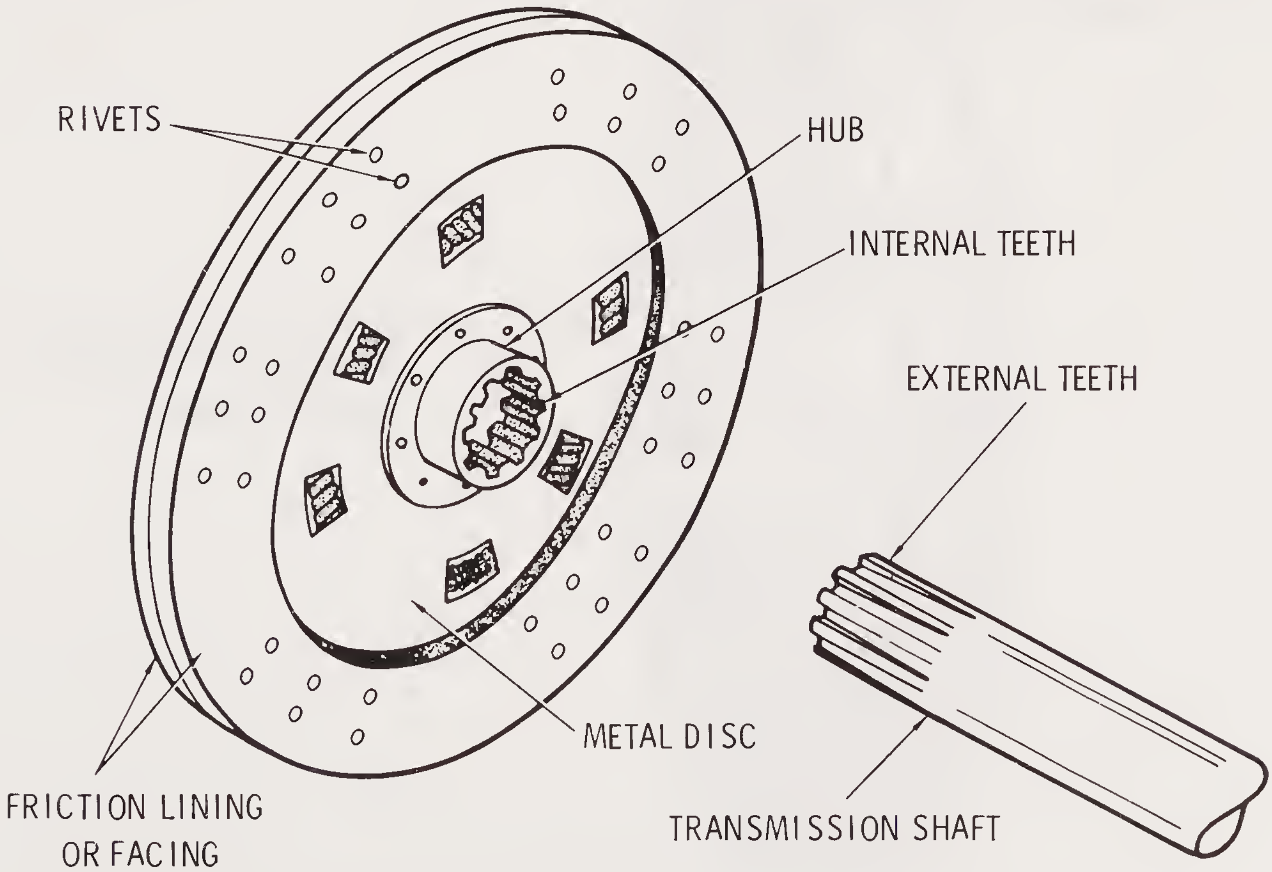



**Fig. 19-3. Driven clutch plate or friction disc.**

The friction liner or facing is attached to the disc with rivets. These linings are easily renewable when worn.

## Cushioning Devices

In order to make clutch engagement as smooth as possible and eliminate "chatter," various cushioning devices are employed, such as crimped spring segments, coiled springs, etc. These devices are shown in Fig. 19-4.

As noted in the illustration, a number of crimped spring steel cushion segments are placed between the rear lining and disc. These segments constitute an independent cushioning means for the lining. The objects of these segments is to eliminate any possibility of clutch chatter or jerk when engaging the clutch. These segments

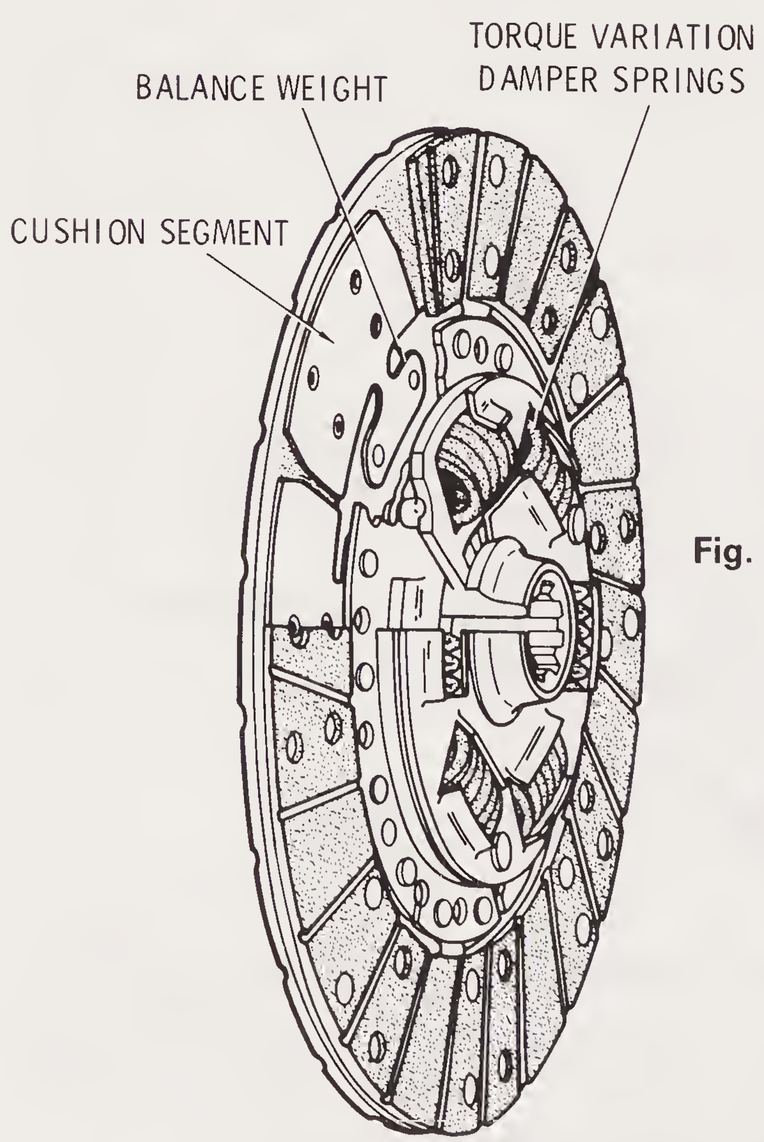



**Fig. 19-4. Driven clutch plate assembly showing cushioning devices.**

also aid in prolonging the life of the lining, as they assist in giving a nearer uniform wear over the entire contacting surface.

Fig. 19-4 shows six coiled springs mounted concentrically with the disc hub. These are cushion springs and form the only means of contact between the hub and the disc carrying the friction facings. By this method, torque impulses of the engine are cushioned out before being transmitted to the spline shaft of the transmission.

# CHAPTER 20

# Electrical System

The electrical system employed on modern internal combustion engines consists of numerous electrical components connected together in various ways to form a circuit or circuits. Principally, the electrical system consists of the following:

1. The ignition system (battery or magneto).
2. The generating system.
3. The starting system.
4. The lighting system (when used).

**Note:** Most modern vehicles use an alternator instead of a generator. In the following text, the word *generator* is used to denote either a d.c. generator or an a.c. alternator.

## STORAGE BATTERY

The storage battery may be considered as the central unit of the electrical system, because the various circuits or paths that carry

electricity to the operating units begin and terminate there. Thus, in tracing circuits and in hunting trouble, the battery is the reference point from which other observations and tests are conducted.

The battery supplies the electric current for operating the starting motor, and such other units as are needed, until the generator comes into action. Also, when the generator is operating but is not producing sufficient current for all purposes, the battery supplements its output. The battery is normally maintained in a charged condition by the electric current produced by the generator. See Fig. 20-1.

The storage battery is an electrochemical device for converting chemical energy into electrical energy. The amount of electrical power in a storage battery is determined by the amount and state of the chemical substance in the battery. When these substances have been used up, they are restored to their original chemical condition by passing an electric current through the battery. This is known as *charging* the battery. When the generator is not producing the necessary electrical energy, the battery, through chemical reaction, can supply the energy required. The battery is then said to be *discharging.*

## Storage Battery Construction

The storage battery of the automotive type consists of three or more cells, depending on the voltage desired. Thus, a battery of three cells, of 2 volts each, connected in series, is known as a *6-volt battery* and one of six cells connected in series is known as a *12-volt battery.*

Each cell of the battery consists of a hard-rubber or plastic compartment into which are placed lead plates, known as *negative* and *positive.* These plates are insulated from each other by suitable separators and are submerged in a solution of sulfuric acid and water. Fig. 20-2 illustrates the parts of a storage battery.

After the plates have been formed, they are connected into *positive* and *negative* groups. The negative group of plates has one more plate than the positive group, to provide a negative plate on both sides of all positive plates.

The assembly of a positive and negative group together with the separators is called an *element.* Because storage battery plates

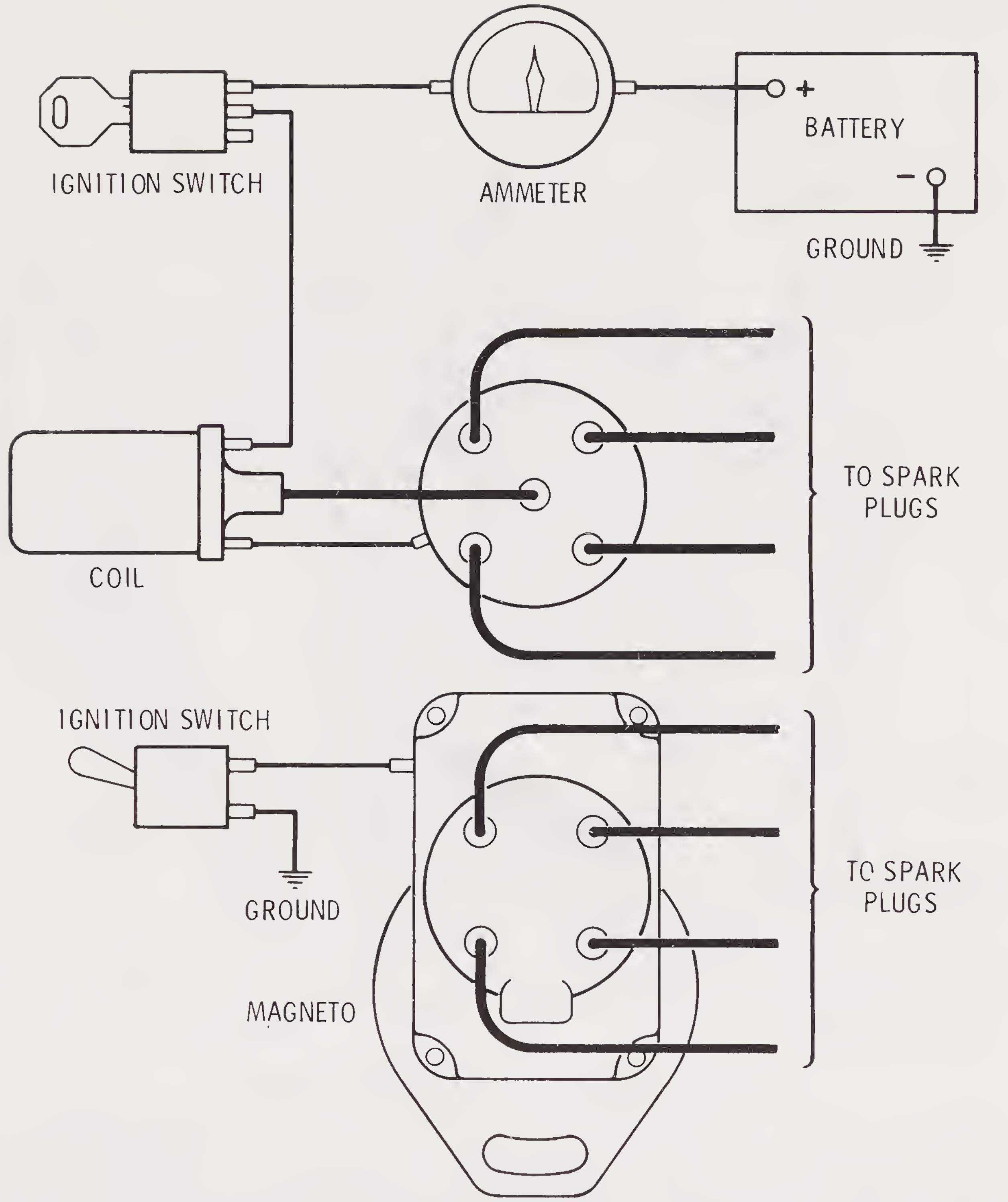



**Fig. 20-1. Schematic wiring diagram showing essential parts of a typical battery and magneto ignition system.**

are more or less of standard size, the number of plates in an element is roughly a measure of battery capacity.

The distance between the plates of an assembled element is approximately $^1/_8$ in. To prevent the plates from touching one another and causing a short circuit, sheets of insulating material, usually wood, porous rubber or spun glass, are inserted between the plates. These easily pass between the plates.

With the elements in place, the covers are pressed on and the

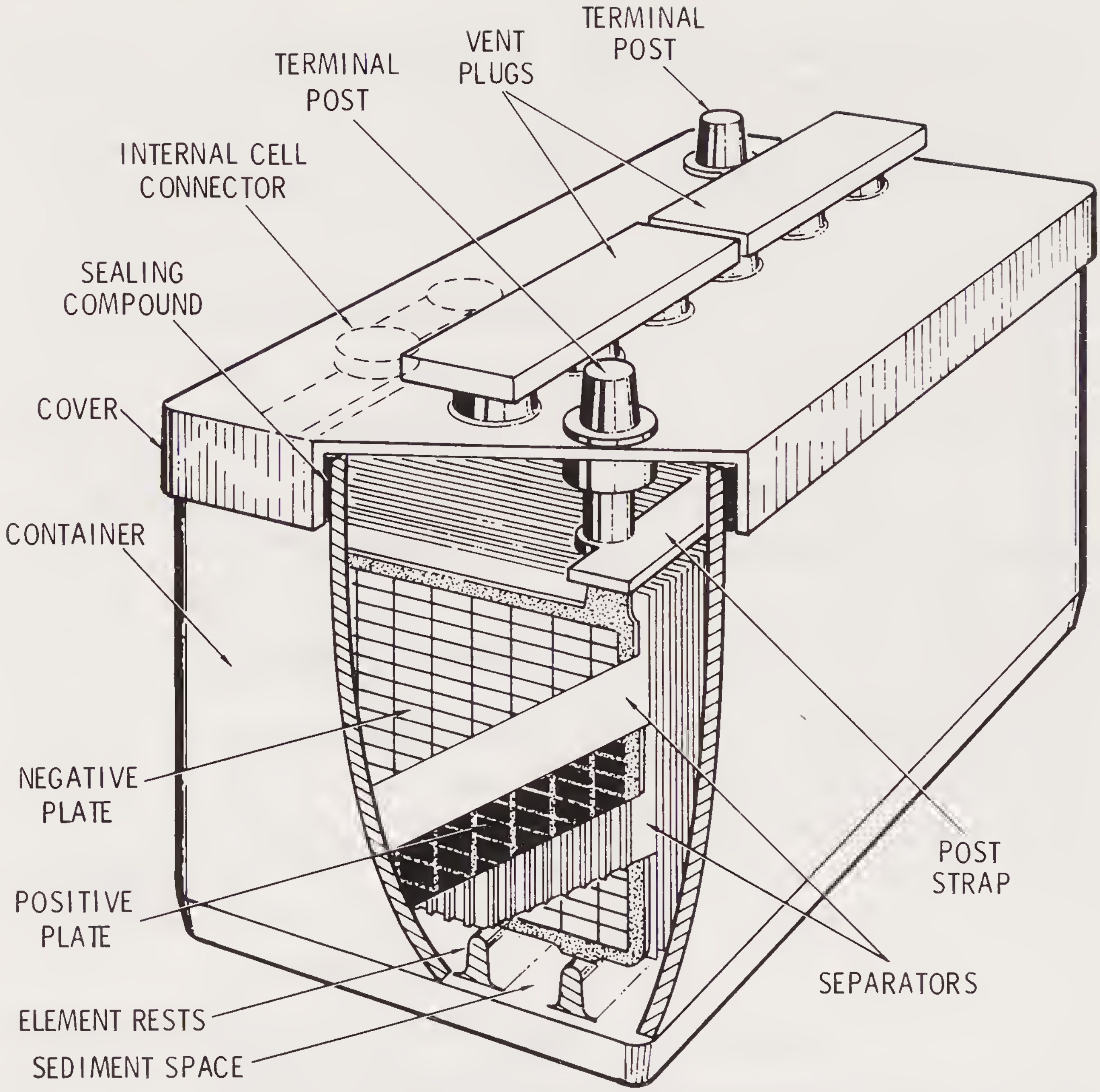



**Fig. 20-2. Typical lead-acid storage battery.**

compartments are sealed. The cells are then connected together by short, heavy bars of lead, called *top connectors*, as shown in Fig. 20-3. A top connector is fused or "burned" to the positive post of one element and the negative post of the element in the adjoining cell.

When all top connectors are in place, there will be one unconnected positive and negative cell at each end of the assembly. These are know as the terminal posts. It is to these terminal posts that the cables of the electric circuit are attached.

## Electrolyte

When the assembly is complete, the electrolyte is poured into the cells to cover the plates and insulation. The electrolyte is prepared

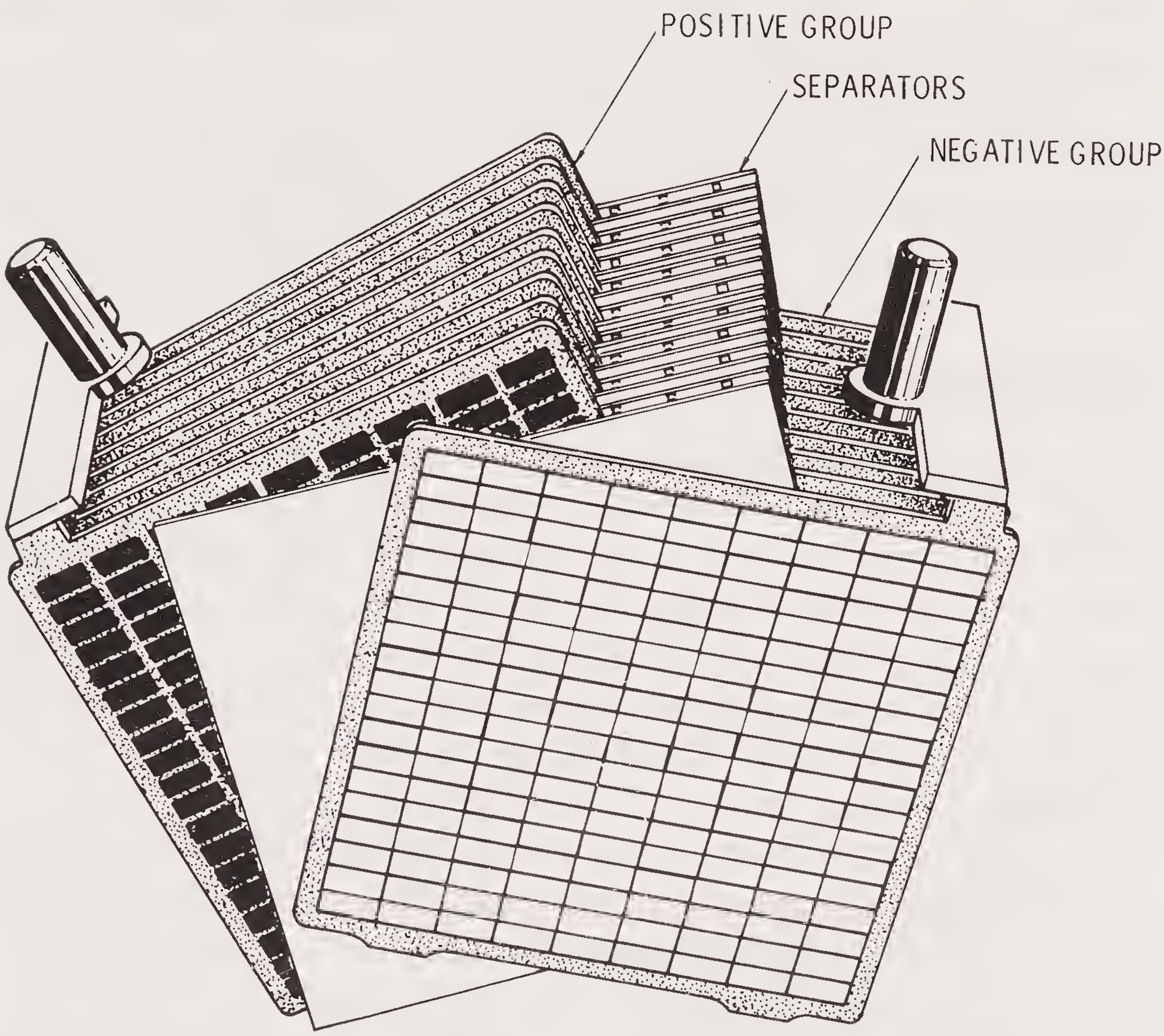



**Fig. 20-3. Negative and positive group of storage battery plates and separators.**

by mixing chemically pure sulfuric acid and pure water. In a fully charged battery, the proportions are approximately five parts water to two parts of sulfuric acid. After the plates have soaked in this solution for a short period of time, the battery is connected to a suitable source of electric current and charged.

## Specific Gravity

By *specific gravity* is meant the weight of a substance compared to the weight of the same volume of chemically pure water at a temperature of 4°C. Since the specific gravity of sulfuric acid is 1.835, it simply means that sulfuric acid is 1.835 times heavier than an equal volume of water when both liquids are at the same temperature. The electrolyte of a storage battery is a mixture of water and

sulfuric acid in such proportions that when the battery is fully charged, it has a specific gravity of 1.280.

Because the amount of sulfuric acid in the electrolyte changes with the amount of electrical charge, the specific gravity of the electrolyte also changes with the amount of charge. This provides a convenient way of measuring the degree of charge in a battery.

## Hydrometer

The specific gravity of an electrolyte can conveniently be measured with a hydrometer syringe. The hydrometer used for testing batteries is provided with a specific-gravity scale graduated from 1.100 to 1.300. The heavier the liquid drawn into the tube, the greater its buoyancy and the higher the float will extend above the surface of the liquid. Liquids having a low specific gravity are less buoyant, and will cause the hydrometer float to sink deeper into the liquid. See Fig. 20-4.

A fully charged battery has a specific gravity reading of 1.280 to 1.300, while the specific gravity of a discharged battery may be as low as 1.150. A specific gravity reading of 1.200 and 1.215 indicates that the battery is more than half discharged. For convenience, the reading is spoken of as being 1150, 1200, 1280, etc., instead of 1.150, 1.200, 1.280 etc., which is the true specific gravity. After measurement the electrolyte is returned to the cell by compressing the bulb, and the reading of the next cell can be taken.

## Temperature Corrections

In this connection it should be noted that the specific-gravity reading of a battery varies with the temperature of the electrolyte. Hydrometers are generally calibrated so as to give accurate readings at 80°F. for the electrolyte. This refers to the temperature of the liquid itself and not the temperature of the surrounding atmosphere.

Correction can be made for temperature by adding .004 (usually referred to as 4 *points of gravity*) to the hydrometer reading for every 10°F. that the electrolyte is above 80°F. or subtracting .004 for every 10°F. that the electrolyte is below 80°F.

If the electrolyte temperature is not too far from the 80°F.

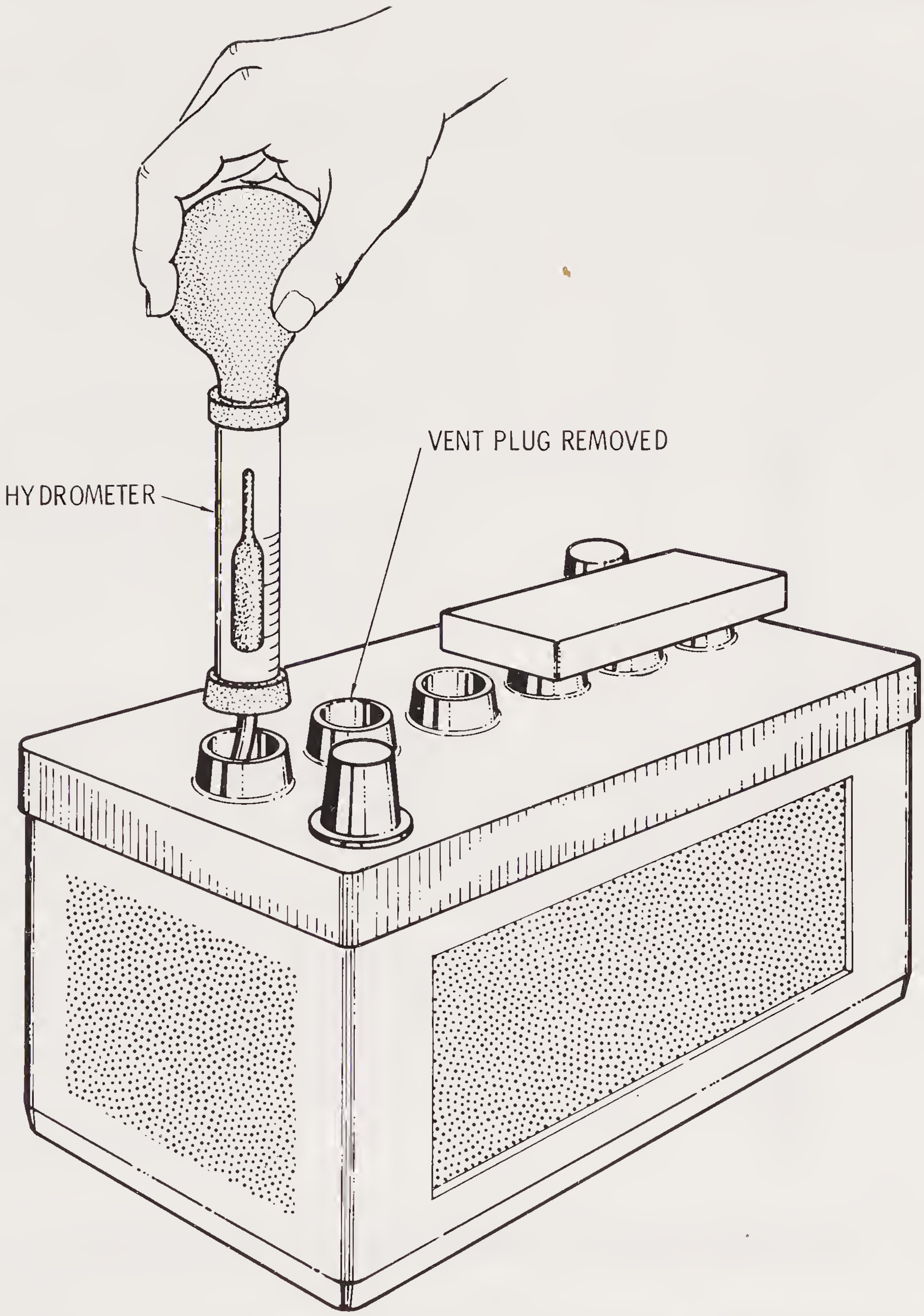



**Fig. 20-4. Hydrometer method of specific gravity test.**

standard, or if only an approximate idea of the specific-gravity reading is required, it will not be necessary to make the temperature correction. There are hydrometers available which have built-in thermometer and temperature scale correction, which, if used, will simplify the operation of obtaining a true specific-gravity reading. See Fig. 20-5.

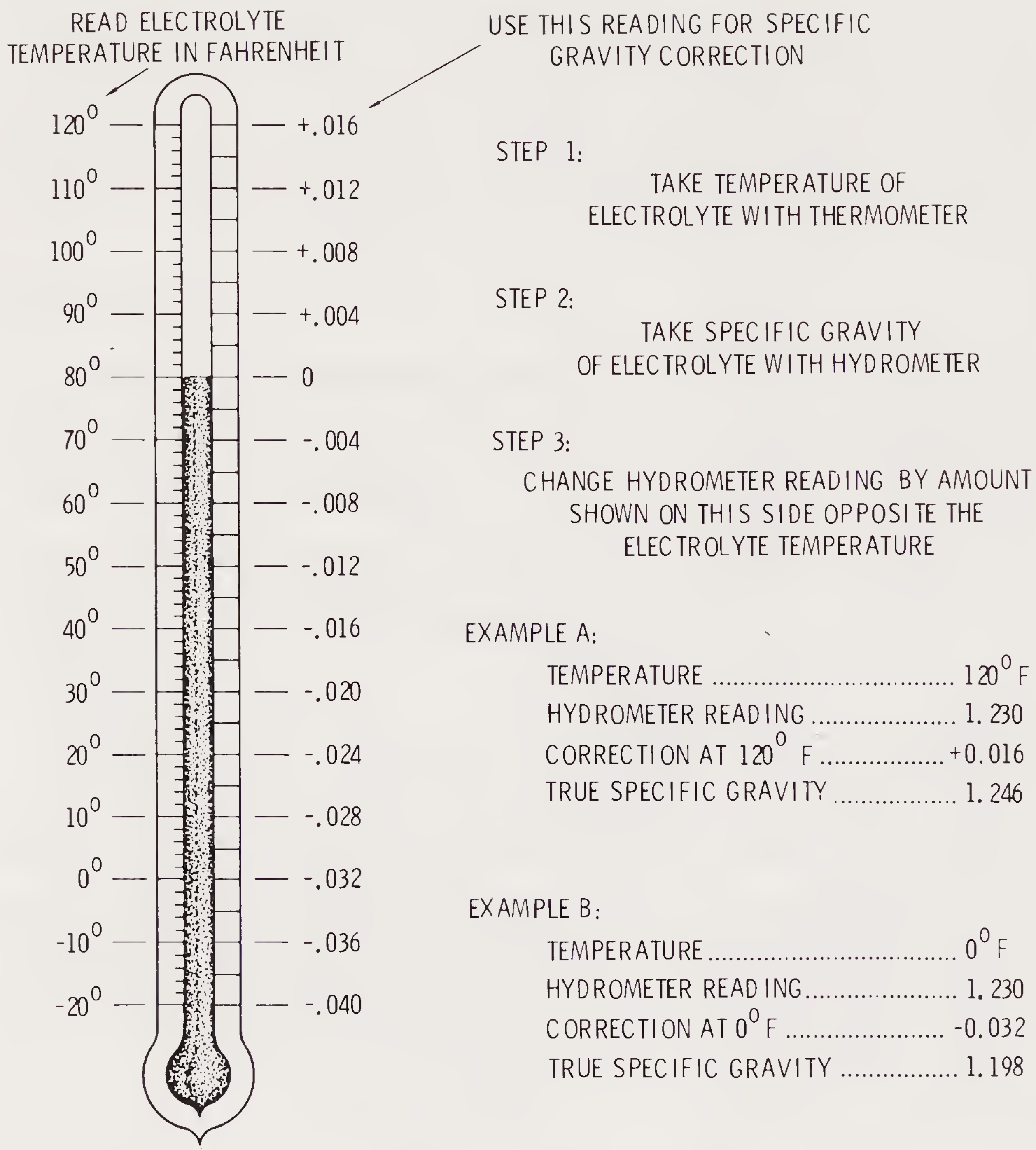



**Fig. 20-5. Specific gravity temperature correction scale.**

## Chemical Action

When a cell is fully charged, the active material of the negative plates consists of spongy lead (Pb) and the active material on the positive plates is lead peroxide ($PbO_2$). The specific gravity of the electrolyte (sulfuric acid, $H_2SO_4$, and water, $H_2O$) is then at its maximum and the cell is capable of delivering electricity when connected to a circuit.

## Discharge

As the cell is delivering current—that is, discharging—the chemical action that takes place changes both the lead (Pb) of the negative plate and the lead peroxide ($PbO_2$) of the positive plate to lead sulfate ($PbSO_4$) and the sulfuric acid ($H_2SO_4$) to water ($H_2O$).

The decomposition of the sulfuric acid and the formation of water dilutes the remaining acid, thus lowering the specific gravity of the electrolyte. As the discharge progresses, the negative and positive plates finally contain considerable lead sulfate. The discharge should always be stopped before the plates have become entirely changed to lead sulfate.

## Charge

To charge the cell, an external source of direct current must be connected to the battery terminals. The chemical reaction is then reversed and the lead sulfate on the positive plates is converted into lead peroxide ($PbO_2$) again, while the lead sulfate on the negative plates is changed back to spongy lead (Pb). The $SO_4$ from the plates combines with hydrogen to form sulfuric acid ($H_2SO_4$), and the electrolyte gradually becomes stronger until no more sulfate remains on the plates. The electrolyte will then be of the same specific gravity as before the discharge.

## Charging Methods

A storage battery can be charged with direct current only. If only alternating current is available, a motor-generator or a rectifier must be used to convert it into direct current.

When connecting the battery terminals to the charging equipment, the positive wire of the charging circuit must always be connected to the positive terminal of the battery, and the negative wire to the negative terminal. The electrolyte in each cell should be brought to the proper level by addition of pure water before the battery is connected for charging.

If several batteries are to be charged at the same time and connected in series, the positive terminal of one battery should be connected to the negative terminal of the next battery. The positive

terminal of the end battery of the series is then connected to the positive terminal of the charging source, and the negative terminal of the series of batteries is connected to the negative terminal of the charging source.

There are two methods of charging batteries, namely the *constant current* (Fig. 20-6) and the *constant voltage.* The constant-current method is used extensively, particularly where the condition of the battery is not fully known. There are no exact values as to the charging rate, but a safe rate would be equal to one-half of the number of plates in the cell. Thus, for example, the charging current of a thirteen-plate cell would be 6.5 amperes, and for a seventeen-plate cell, approximately 8.5 amperes. Also, where several batteries are connected in series for charging, the charging current is determined by the size of the smallest battery in the circuit. See Fig. 20-7.

The temperature of the battery should be watched carefully during all stages of the charging process. It should be checked frequently with a thermometer, and if it rises above 110°F. either the current should be shut off until the battery is cool or the charging rate reduced. Proper ventilation should be provided when charging batteries.

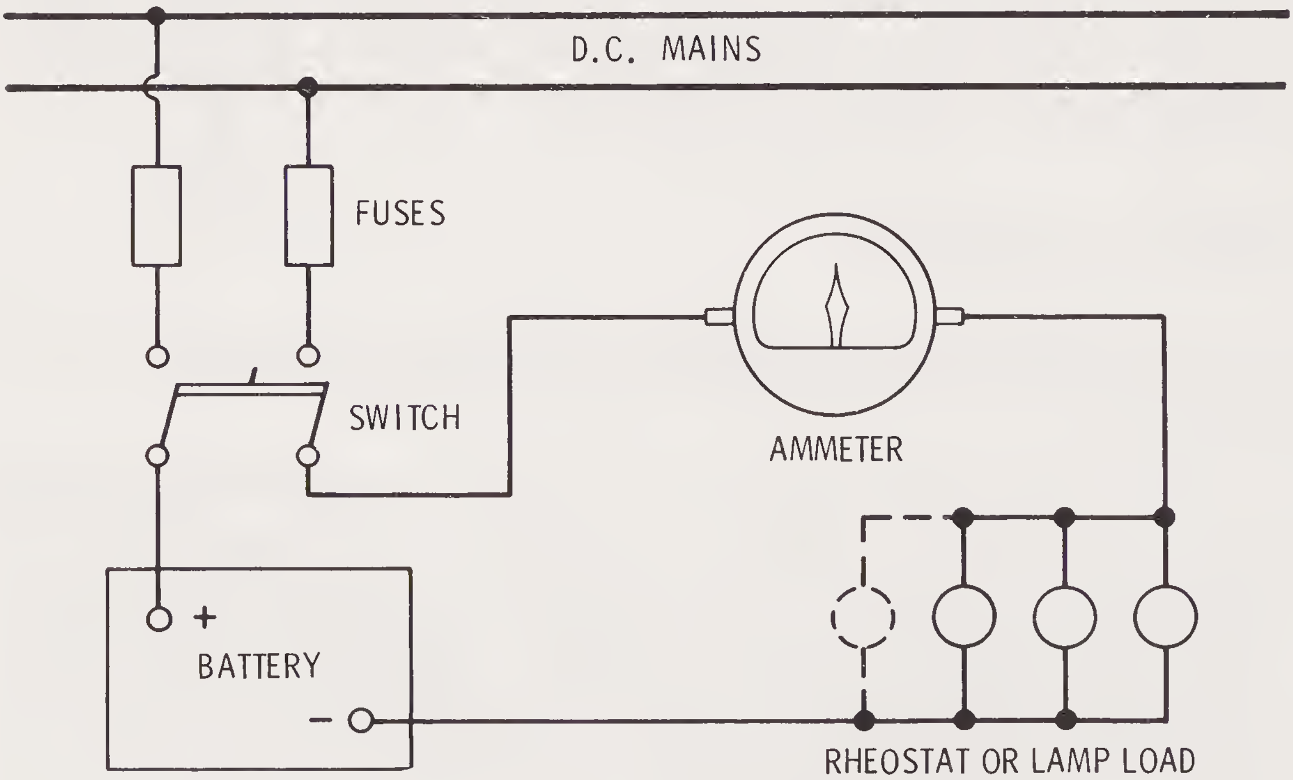



**Fig. 20-6. Wiring diagram illustrating hookup for constant-current battery charging.**

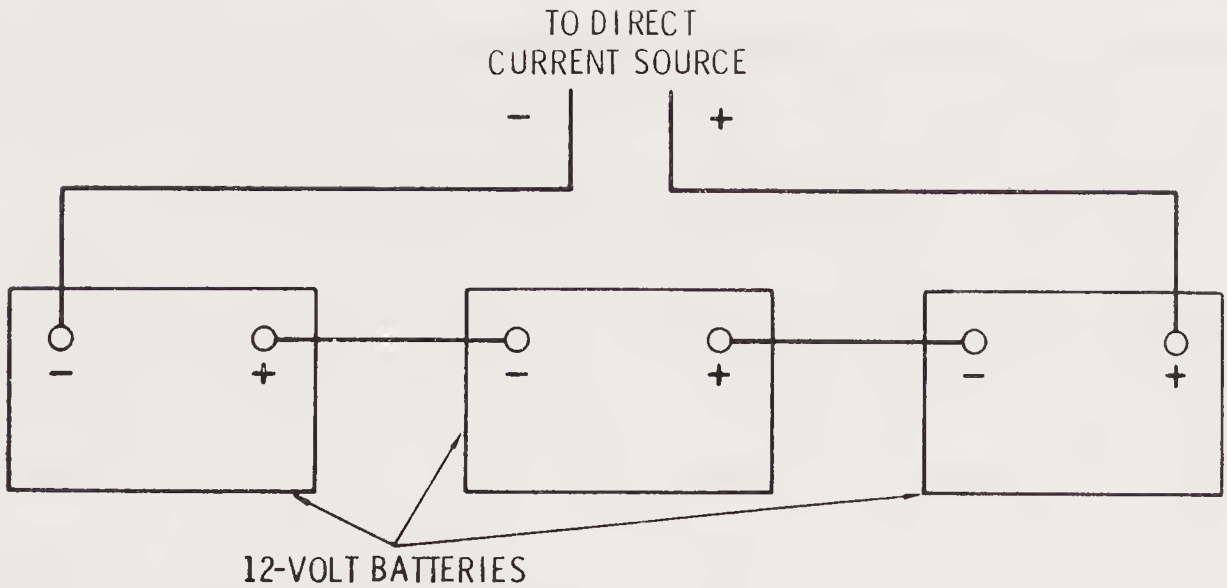



**Fig. 20-7. Wiring diagram of a series hookup for constant-current battery charging.**

As a battery approaches a charged condition, gas bubbles commence to appear at the surface of the electrolyte. This is known as *gassing*. All cells should gas freely when the battery is fully charged. If a cell does not gas, either the cell is not charged or else there is some internal trouble. Excessive charging will damage the battery, particularly the positive plates. Depending on the charging rate, most batteries can be charged in 12 to 16 hours, although batteries with sulfurated plates may require a much greater charging period.

*Constant voltage charging*, as the name implies, maintains the same voltage throughout the charging period, and as a result the current is automatically reduced as the battery approaches full charge. When properly done, this method has been found generally satisfactory for recharging of batteries which are in good working condition, and it has the advantage of completing the charging process in a minimum of time. This method is the type employed on all modern automotive electrical systems. A badly sulfurated battery may not, however, come up to charge when this charging method is used.

## Battery Ratings

All batteries are given a normal capacity rating according to the number of ampere-hours obtained from the battery under certain working conditions. The 20-hour rating has been accepted as standard by the American Society of Automotive Engineers for auto-

motive batteries. To measure the capacity, a battery is discharged continuously at a specific rate until the voltage drops too low for efficient use. Thus, for example, a battery that will deliver 6 amperes for 20 hours is said to have a capacity of 120 ampere-hours.

This measurement is of particular interest because it indicates what may be expected of a battery in the way of satisfactory performance. The capacity of a battery depends on the amount of active material that can react with the electrolyte. Obviously, this depends on the thickness and design of the plates; hence the number of plates is not always an accurate index of the capacity.

Also, one of the characteristics of a storage battery is that its total ampere-hour capacity is dependent on the rate of discharge. The lower the rate of discharge, the greater the ampere-hour capacity will be; whereas the higher the discharge rate, the lower will be the capacity. Thus, a battery having a 120 ampere-hour capacity at a 6-ampere discharge rate will ordinarily have a capacity of over 120 ampere-hours at a lower discharge rate.

## New Battery Rating Systems

The ampere-hours rating system is being replaced by a more accurate system termed *cold cranking rating.* The old system was based on the number of ampere-hours a fully charged battery would produce when operating at maximum discharge rate for 20 hours without falling below 10.5 volts at 80°F. Therefore, ratings in ampere-hours were tested at relatively low current flow compared to starting current. This did not yield a rating of a battery's ability to start an engine, considered the most critical measure.

Cold cranking rating specifies the maximum discharge rate the battery will withstand for 30 seconds and remain above 7.2 volts at 0°F. This system is an accurate measure of a battery's ability to start a cold engine. It is very convenient, since most manufacturers specify a 1-ampere cold cranking rating for each cubic inch of engine displacement.

An additional rating found on most batteries sold today is *reserve capacity.* This rating represents the approximate operating period the battery will withstand without a charging system. This rating is based on the time, in minutes, the battery will withstand

a 25-ampere load, simulating combined ignition system vehicle accessory load, while maintaining 10.2 volts.

## GENERATING SYSTEM

The function of the generating system is to restore to the battery the energy used during periods when the generating system is *not* in operation (as when the engine is being cranked to a start), and to take over from the battery and supply all of the vehicle's electrical energy requirements whenever the engine is running at sufficient speed to make the generating system fully operative. The engine speed at which the generating system will produce all the energy needed usually varies from idle to somewhat more, depending on the electrical devices (lights, radio, etc.) in use at the moment.

The generating circuit is designed so that the battery "floats on the line"; that is, when the system is delivering sufficient current, the excess above vehicle requirements serves to keep the battery in a charged condition. When the system, due to low engine speed, is *not* delivering sufficient current, the battery furnishes the excess current needed.

There are two general types of generating systems. The type first used for vehicles consists of a *d.c. generator*, a *generator-regulator* (which is one unit incorporating three devices: a *cutout relay*, *current regulator* and *voltage regulator*) and the battery and wires or cables needed for connecting these various units. Now mostly used is the type of system that consists of an *a.c. alternator*, a *voltage regulator*, a *rectifier* and the battery and wires or cables needed. This latter system is preferred because the output of an alternator is directly related to the voltage applied to its field, whereas a generator produces voltage and current in relation to the speed at which it is being operated. Consequently, an alternator can be designed to produce current even at engine low-idling speed, and no engine power is wasted in producing unneeded current. On the other hand, a generator must be operated at an engine fast-idle speed (or better) to produce even enough current for the ignition system, builds up the output rapidly so that both voltage and current regulation are required, and wastes some engine power. Moreover, a generator requires a cutout relay (to prevent reversal of current

from the battery through the generator), whereas an alternator has a rectifier circuit, which accomplishes this without mechanical operation.

## D.C. Generator System

Most automotive-type generators are of the shunt-wound type with an outside means of regulating the voltage output. A typical d.c. generator (Fig. 20-8) consists essentially of an armature revolving within a magnetic field, and its components consist of a commutator, spring-loaded brushes, shaft, bearings, etc., all mounted within a sturdy frame.

The generator is commonly mounted on a bracket on the side of the engine and is driven by the fan belt. This method of mounting permits the generator to be moved in or out to adjust tension of the fan belt.

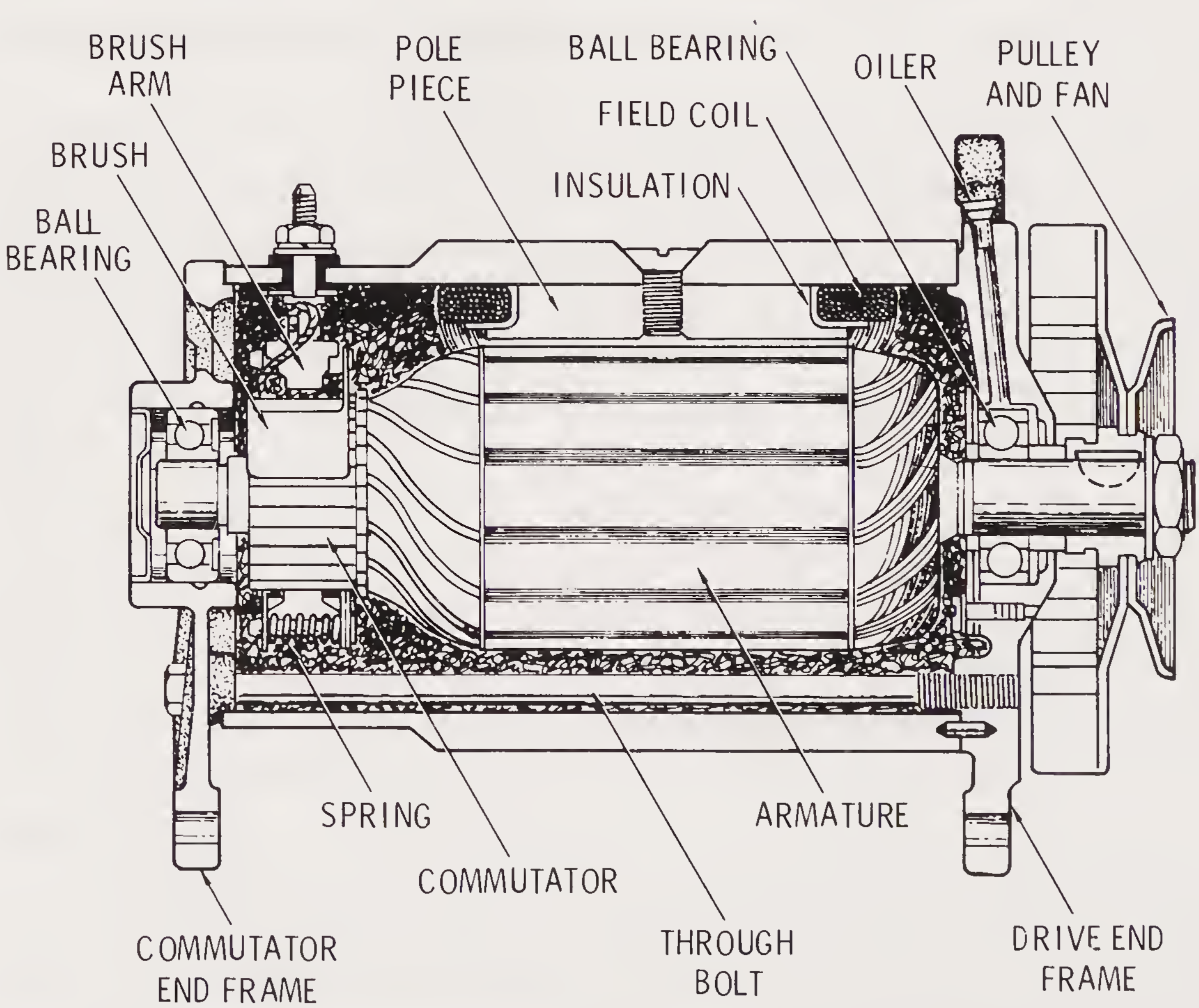



**Fig. 20-8. Cross section showing construction of typical direct current generator.**

## Essential Controls

In any electric system such as that shown in Fig. 20-9, where there is a generator and battery, two control elements are necessary for the proper working of the system. They are:

1. Means of preventing reversal of current when generator is not charging the battery.
2. Means of limiting generator voltage.

The generator cutout relay acts as an automatic switch to connect the generator to the battery when the generator voltage exceeds that of the battery. When the battery voltage exceeds that of the

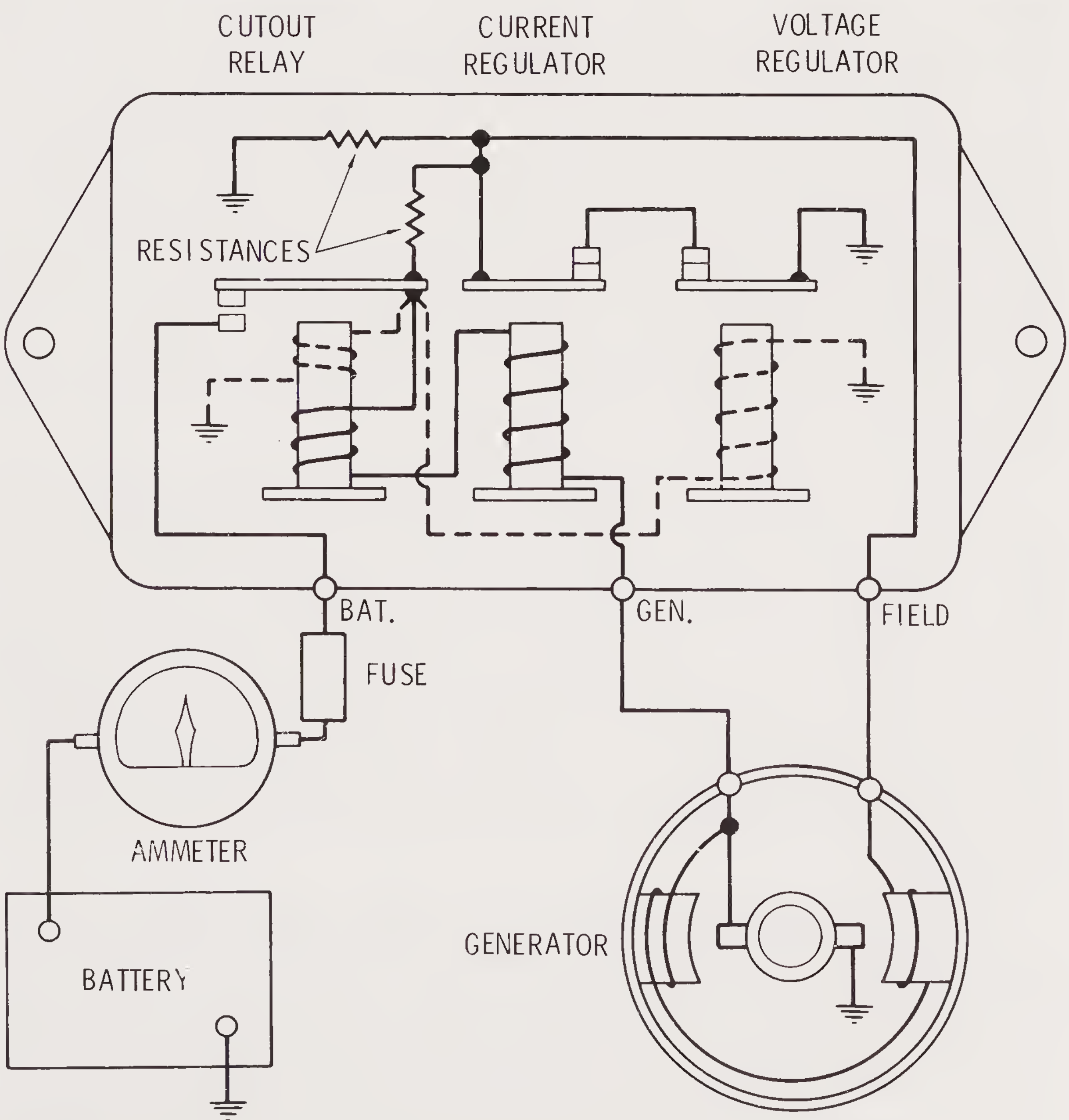



**Fig. 20-9. Wiring diagram of typical generator regulator unit.**

generator, the cutout relay points open to prevent the battery from discharging through the generator.

The voltage and current regulators control the amount of voltage and current the generator produces, allowing the generator to produce a high current when the battery is in a discharged condition, and the lights and other accessories are turned on, while maintaining a constant voltage. When the battery is charged and the electrical accessories are disconnected, the regulator reduces the current produced to the amount needed to meet the operating requirements of the system.

## Cutout Relay

The cutout relay has a series or current winding of a few turns of heavy wire, and a shunt or voltage winding of many turns of fine wire, both assembled on the same core. The shunt winding is connected between generator armature and ground so that generator voltage is impressed on it at all times. The series winding is connected so that all generator output current must pass through it. It is connected to a flat steel armature which has a pair of contact points through which current passes to the battery and other electrical units. The contact points are held open by armature spring tension when the units is not operating.

When the generator begins to operate, voltage builds up and forces current through the shunt winding, thereby magnetizing the core. When the voltage reaches the value for which the relay is set, the magnetism is strong enough to overcome the armature spring tension and pull the armature toward the core, thereby closing the contact points. Generator current now flows through the relay windings in the right direction to add to the magnetism holding the points closed, and passes on to the battery and other electrical units in operation.

When the generator slows to engine idling speed, or stops, current begins to flow from the battery back through the generator, reversing the current flow through the series winding. This reduces the magnetism of the relay core to the extent that it can no longer hold the contact points closed against armature spring tension. The points are separated and the circuit broken between the generator and battery.

Most regulators have a fuse in the generator charging circuit. This fuse connects to the battery terminal of the regulator and the battery lead connects to it in turn. The purpose of the fuse is to protect the generator and wiring should a stuck or welded cutout relay occur. Shorts or grounds occurring in the charging circuit or reverse polarity conditions of the generator can cause the cutout relay points to weld together. This allows the battery to discharge through the generator when the generator is not developing greater than battery voltage.

## Current Regulator

The current regulator (Fig. 20-9) automatically controls the maximum output of the generator. When the current requirements of the electrical system are large and the battery is low, the current regulator operates to protect the generator from overload by limiting its output to a safe value.

The current regulator has one series winding of heavy wire through which the entire generator output flows at all times. This winding connects to the series winding in the cutout relay, previously described. Above the winding core is an armature, with a pair of contact points which are held together by spring tension when the current regulator is not operating. When the current regulator is not operating and the contact points are closed, the generator field circuit is directly grounded so that the generator may produce maximum output, unless further controlled by the voltage regulator.

When the generator output increases to the value for which the current regulator is set, the magnetism of the current winding is sufficient to overcome the armature spring tension. The armature is pulled toward the winding core so that the points are separated. The generator field circuit must then pass through a resistance, which reduces the flow through the field coils and thereby reduces the output of the generator. This reduces the magnetic strength of the current winding so that spring tension again closes the contact points, directly grounding the generator field circuit and increasing generator output. This cycle is repeated many times a second, and the action limits the generator output to the value for which the regulator is set.

The current regulator has a bimetallic hinge on the armature

for thermostatic temperature control. This automatically permits a somewhat higher generator output when the unit is cold, and causes the output to drop off as the temperature increases.

The current regulator operates only when the condition of the battery and the load of current-consuming units in operation require maximum output of the generator. When current requirements are small, the voltage regulator controls generator output. Either the current regulator or the voltage regulator operates at any one time; both regulators never operate at the same time.

## Voltage Regulator

The voltage regulator (Fig. 20-9) limits the voltage in the charging circuits to a safe value, thereby controlling the charging rate of the generator in accordance with the requirements of the battery and the current-consuming electrical units in operation. When the battery is low, the generator output is near maximum, but as the battery comes up to charge and other requirements are small, the voltage regulator operates to limit the voltage, thereby reducing the generator output. This protects the battery from overcharge and the electrical system from high voltage.

The voltage regulator unit has a shunt winding consisting of many turns of fine wire and which is connected across the generator. The winding and core are assembled into a frame. A slat steel armature is attached to the frame by a flexible hinge so that it is just above the end of the core. When the voltage regulator unit is not operating, the tension of a spiral spring holds the armature away from the core so that a point set is in contact, which allows the generator field circuit to complete the ground through them.

When the generator voltage reaches the value for which the voltage regulator is set, the magnetic pull of the voltage winding is sufficient to overcome the armature spring tension, so that the armature is pulled toward the core and the contact points are separated. The instant the points separate, the field current flows only through the resistance to ground. This reduces the current flow through the field coils and decreases generator voltage and output.

The reduced voltage in the circuit causes a weakening of the magnetic field of the voltage winding in the regulator. The resulting loss of magnetism permits the spring to pull the armature away from

the core and close the contact points again, thereby directly grounding the generator field so that generator voltage and output increases.

This cycle is repeated many times a second, causing a vibrating action of the armature, and holds the generator voltage. The voltage regulator continues to reduce the generator output as the battery comes up to charge. When the battery reaches a fully charged condition, the voltage regulator will have reduced the generator output to a relatively few amperes.

The voltage regulator has a bimetallic armature hinge for thermostatic temperature control. This automatically permits regulation to a higher voltage when the unit is cold, and to a lower voltage when hot, because a high voltage is required to charge a cold battery.

As previously stated, the current and voltage regulators do not operate at the same time. When current requirements are large, the generator voltage is too low to cause the voltage regulator to operate. Therefore, the current regulator operates to limit maximum output of generator. When current requirements are large, the generator voltage is too low to cause the voltage regulator to operate. The generator output is then reduced below the value required to operate the current regulator; consequently, all control is then dependent on the operation of the voltage regulator.

### Resistance

The current or voltage regulator circuit each uses its own resistance, which is inserted in the field circuit when either regulator operates. A third resistance is connected between the cutout relay base plate and the voltage regulator.

The sudden reduction in field current, occurring when either the current or voltage regulator contact points open, is accomplished by a surge of induced voltage in the field coils as the strength of the magnetic fields change. These surges are partially dissipated by the two resistances, thus preventing excessive arcing at the contact points.

## A.C. ALTERNATOR SYSTEM

Though similar in construction to a generator (and mounted on an engine in the same way), an alternator differs somewhat in its elec-

trical design. The rotating part, called a *rotor*, acts as the alternator's field, and the generating component (comparable in function to a generator's armature) is composed of stationary coils surrounding the rotor and called the *stator*. Since the generated "output" current passes through the stationary stator, a generator-type commutator and brushes are *not* needed. Current to activate the rotor is passed to it through one brush and a (circular) slip ring on the rotor, then from the rotor to ground through a second brush and slip ring.

To control output voltage maximum it is necessary only to control the voltage applied to the rotor, and the alternator then tends to limit its output current to the "demands" of the circuits it serves. Voltage control may be accomplished either by a remote electromechanical regulator similar to the voltage regulator used with a generator, or by a transistor regulator, which may be internal. See Fig. 20-10.

Automotive alternators generally have a three-phase (Fig. 20-11) stator which, because current is generated within one or the next of the three windings, tends to "level out" the peaks and valleys

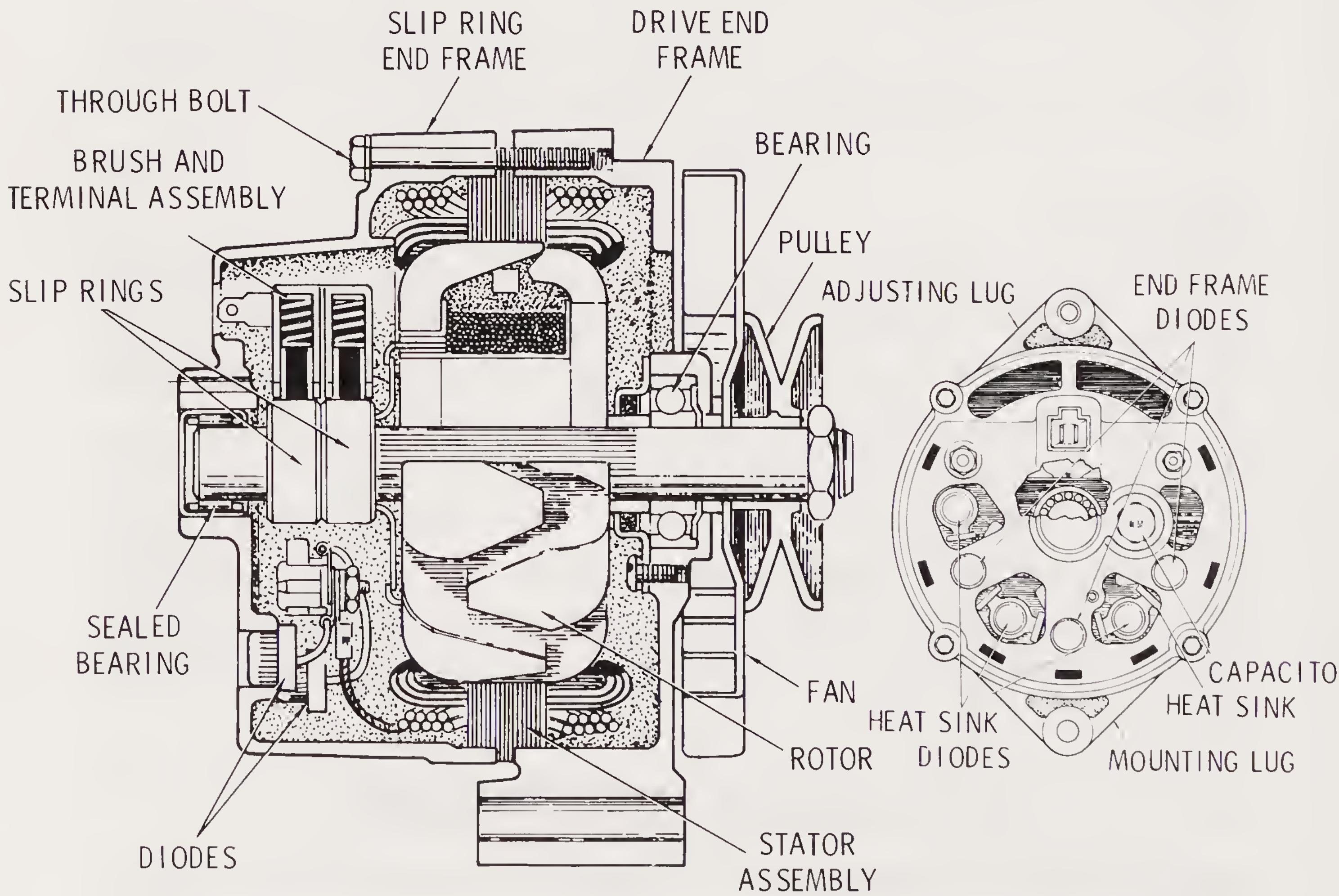



**Fig. 20-10. Typical alternator without an integral regulator.**

of alternating current generation, and to produce a more consistently uniform output voltage. The output is a.c., which is *not* suitable for charging a battery or the ignition system and must therefore be converted to d.c. Conversion is accomplished by a *rectifier bridge*, which accomplishes "full" rectification; that is, *all* of the a.c. is channeled through the circuit so that it comes out "flowing" in the same direction (instead of first in one and then in the other direction as does a.c.) to become an uninterrupted (constant "flowing") d.c. See Fig. 20-11.

A full-rectification bridge requires two rectifiers for each of the three three-phase windings—a total of six, minimum. (In some

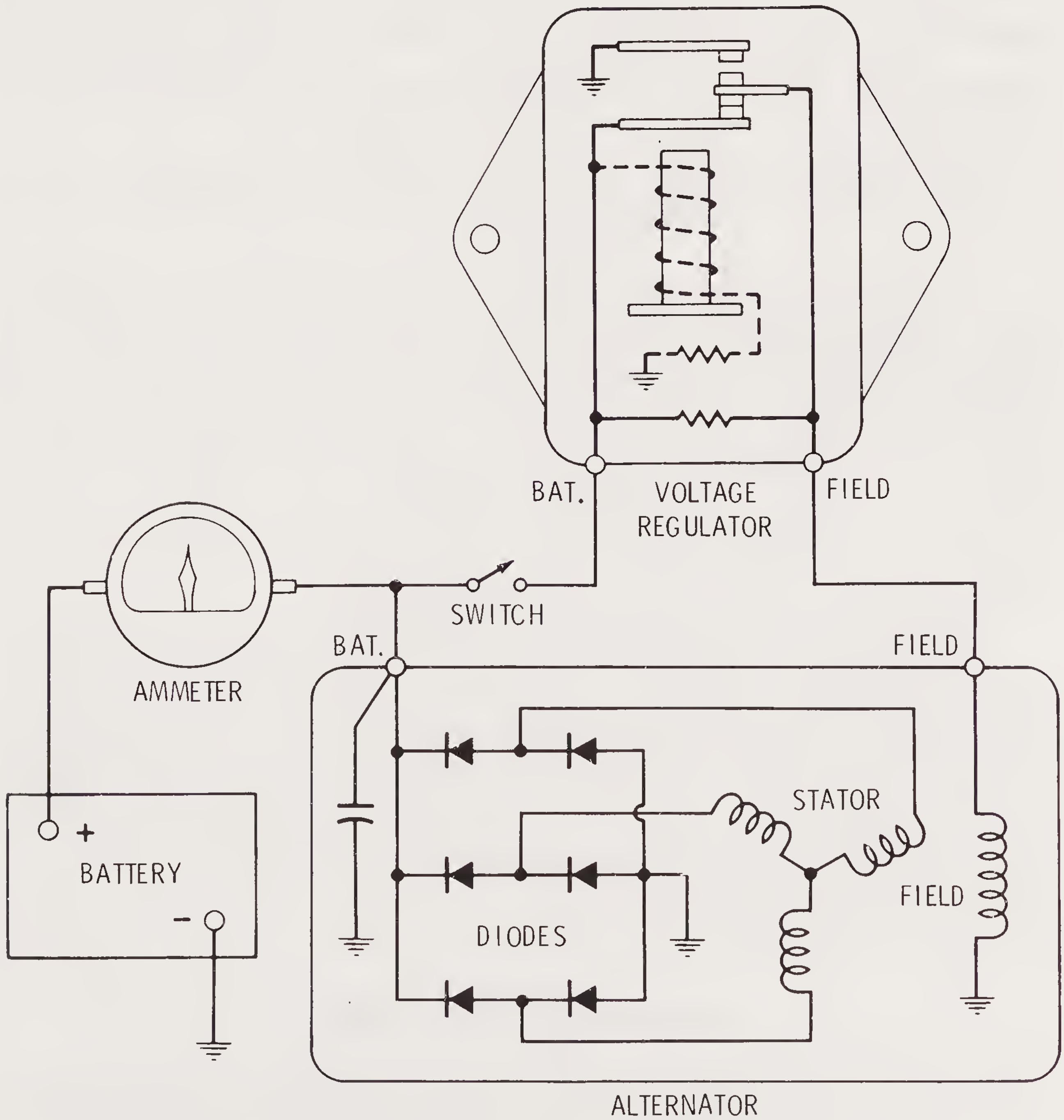



**Fig. 20-11. Alternator charging circuit with external regulator.**

cases, where a separate starting-amp current is desired, an additional pair or trio—for a total of eight or nine—is added into the common connecting line of the delta connection.) The rectifiers used are called *diodes*. These are compact units made of silicon and have the property of freely conducting a current flow in one direction while opposing its flow in the opposite direction. The electrical circuitry of a bridge circuit is such that, while flowing in one direction, a.c. will "flow out through the front door," then, during the part of its cycle that causes it to flow in the opposite direction, "flow out through the back door" into the same external circuit.

Diodes are part of an alternator assembly. They may be press-fitted into one of the alternator-housing end shields or an insulated attachment called a *heat sink*, and wiring to them is internally accomplished. Half of the total number are on the grounded circuit side and the other half are connected to the output.

**Note:** Because each diode, depending on its size, will "pass" only so much current, in some cases two diodes in parallel may be used in place of one.

A *transistor regulator*, as illustrated in Fig. 20-12, consists of an electrical assembly composed of transistors, diodes, resistors, a capacitor and a thermistor. Transistors are devices that limit voltage by controlling current, and the other components assist the transistors. The thermistor adjusts for temperature. Compact in size, this type of regulator generally is mounted in a compact case or within the alternator housing, and wired into the rotor circuit. Such a unit has no provisions for manual adjustment.

When an electromechanical regulator is used, one of the two rotor brushes is grounded, as previously explained. When a transistor regulator is used, either an *insulated brush* or an *isolated field* circuitry may be used. These differ only in the manner in which grounding of the rotor circuit is accomplished. In other words, rotor current can be controlled by limiting current either flowing to the rotor or from the rotor to ground.

## STARTING SYSTEM

Although starting motors resemble generators, they are different in construction and operation. Many general parts, like field coils, armature and brushes, are common to both, but the design of these

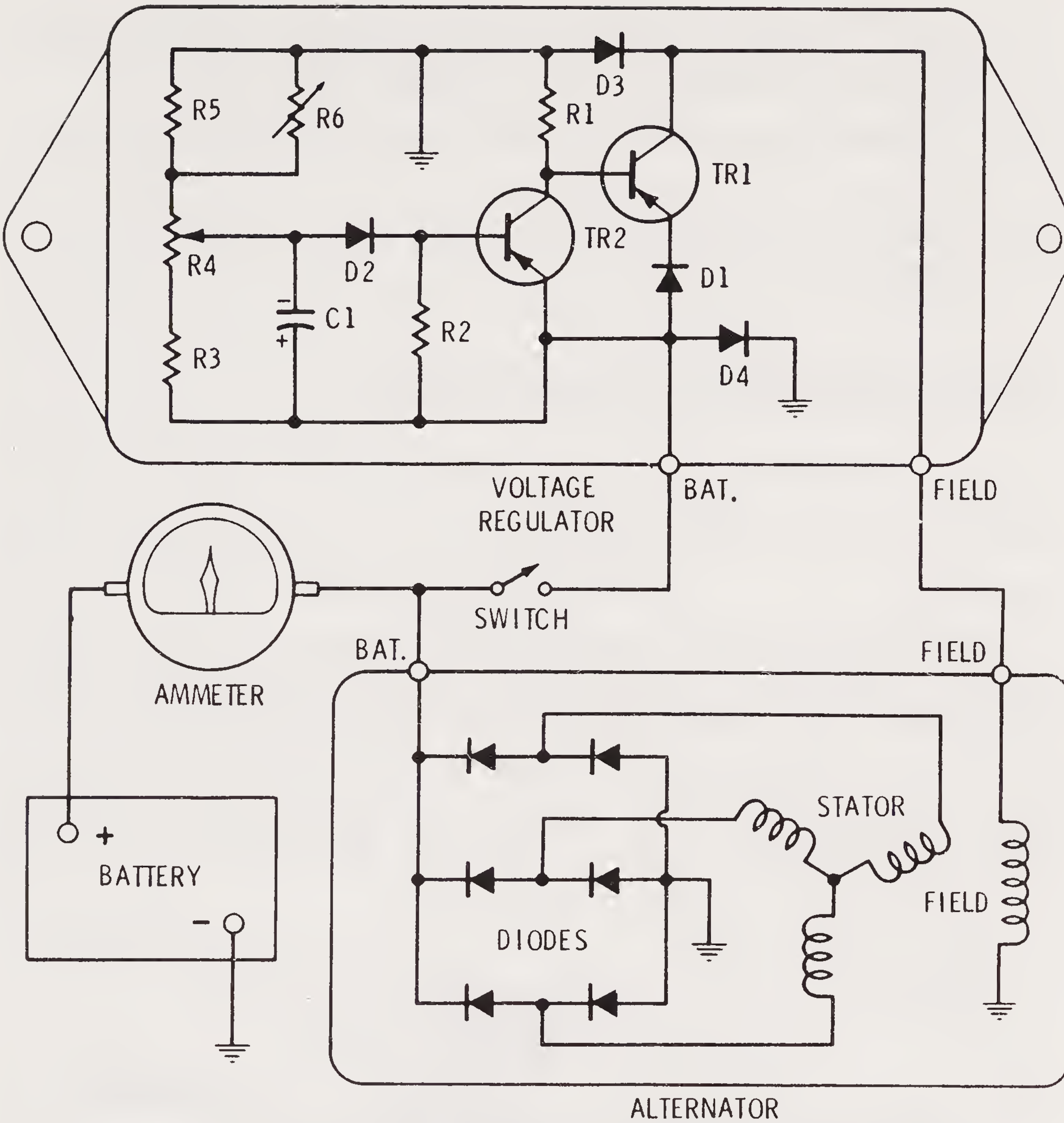



**Fig. 20-12. Alternator charging circuit with a transistor regulator.**

is different. Also, in a generator mechanical energy is converted into electrical energy, whereas in a motor electrical energy is converted into mechanical energy.

The starting motor is a low-voltage series-wound direct current motor that converts electrical energy from the battery into mechanical energy for cranking the engine when the circuit between the battery and the motor is closed.

The means for coupling the motor to the engine when starting is known as the *cranking system.* The cranking system is generally composed of the following units:

1. Battery and battery cables.

2. Cranking motor, including the drive assembly which engages the flywheel ring gear during cranking operation.
3. Cranking motor solenoid switch used for closing the motor circuit.
4. Usually a solenoid mounted on the starter motor for engaging the drive assembly.

## Overrunning Clutch Drive Assembly

In the overrunning clutch drive, the starter motor drives the engine through a pinion attached to the motor armature shaft, which is brought into mesh with teeth cut on the rim of the flywheel. See Fig. 20-13.

Shifting the pinion gear into mesh with the flywheel gear is most commonly done automatically by the use of a solenoid. For operation of the solenoid shift, a remotely operated control switch is necessary. The ignition is connected to the control circuit so that the starting motor will not operate until the ignition is on. The solenoid shift unit is rigidly mounted on the starting motor field

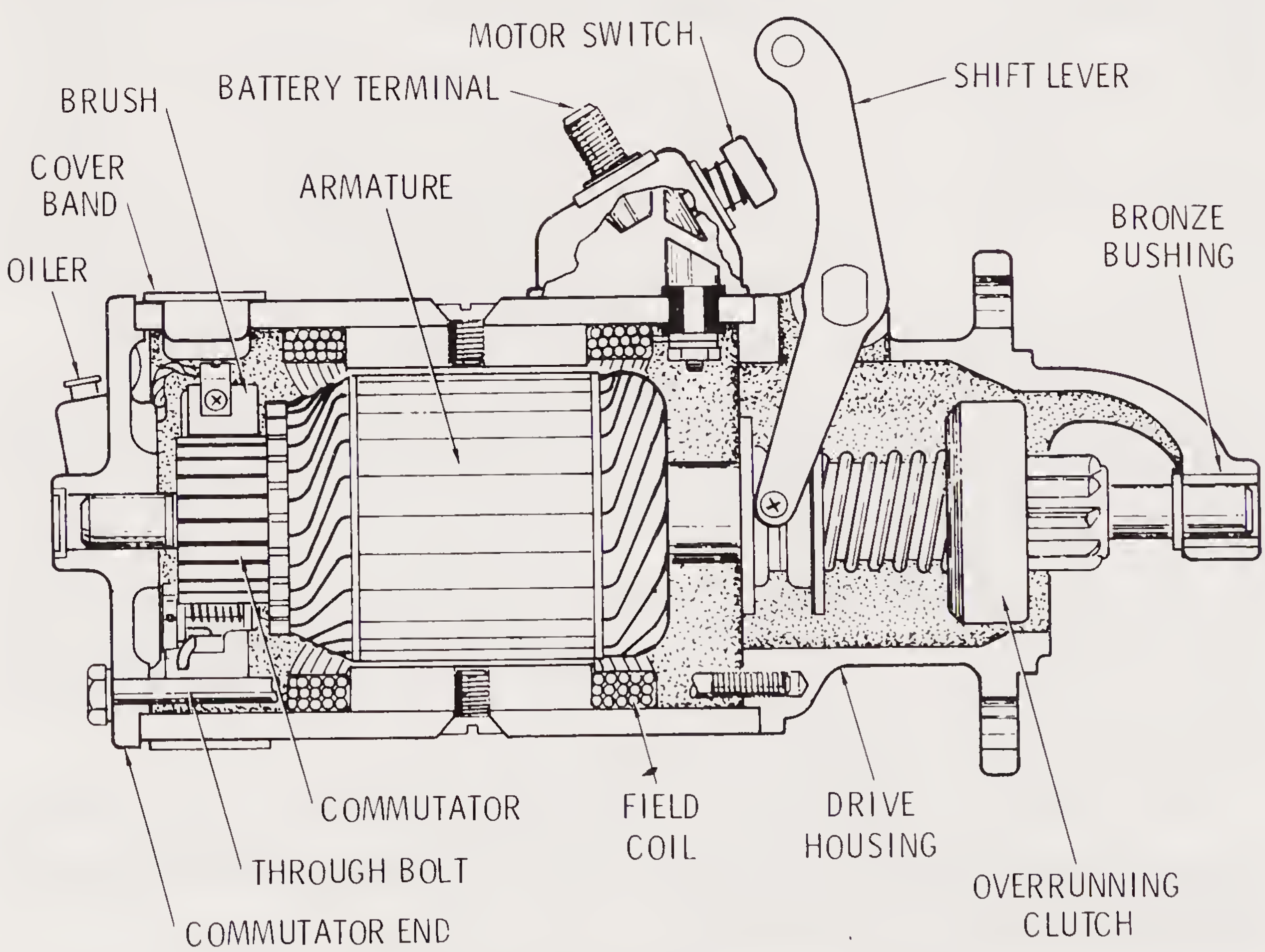



**Fig. 20-13. Sectional view of starting motor with overrunning clutch drive.**

frame. Inside the solenoid coil is a heavy plunger connected to the shift lever as noted in Fig. 20-14.

When the remote control circuit is closed, the solenoid exerts a pull on the shift plunger, which shifts the pinion into mesh with the flywheel teeth. After the pinion shift lever has moved the required distance for meshing the pinion gear, the pointed end of the shift plunger presses against the end of a contact plunger and pushes a contact disc on the contact plunger across the switch contacts to operate the motor. An overrunning clutch is required with this system to prevent damage to the starter at the time the engine fires. See Fig. 20-15.

## Push-Button Control and Solenoids

One method of controlling the solenoid shift is by means of push button on the instrument panel. Pushing the button closes the

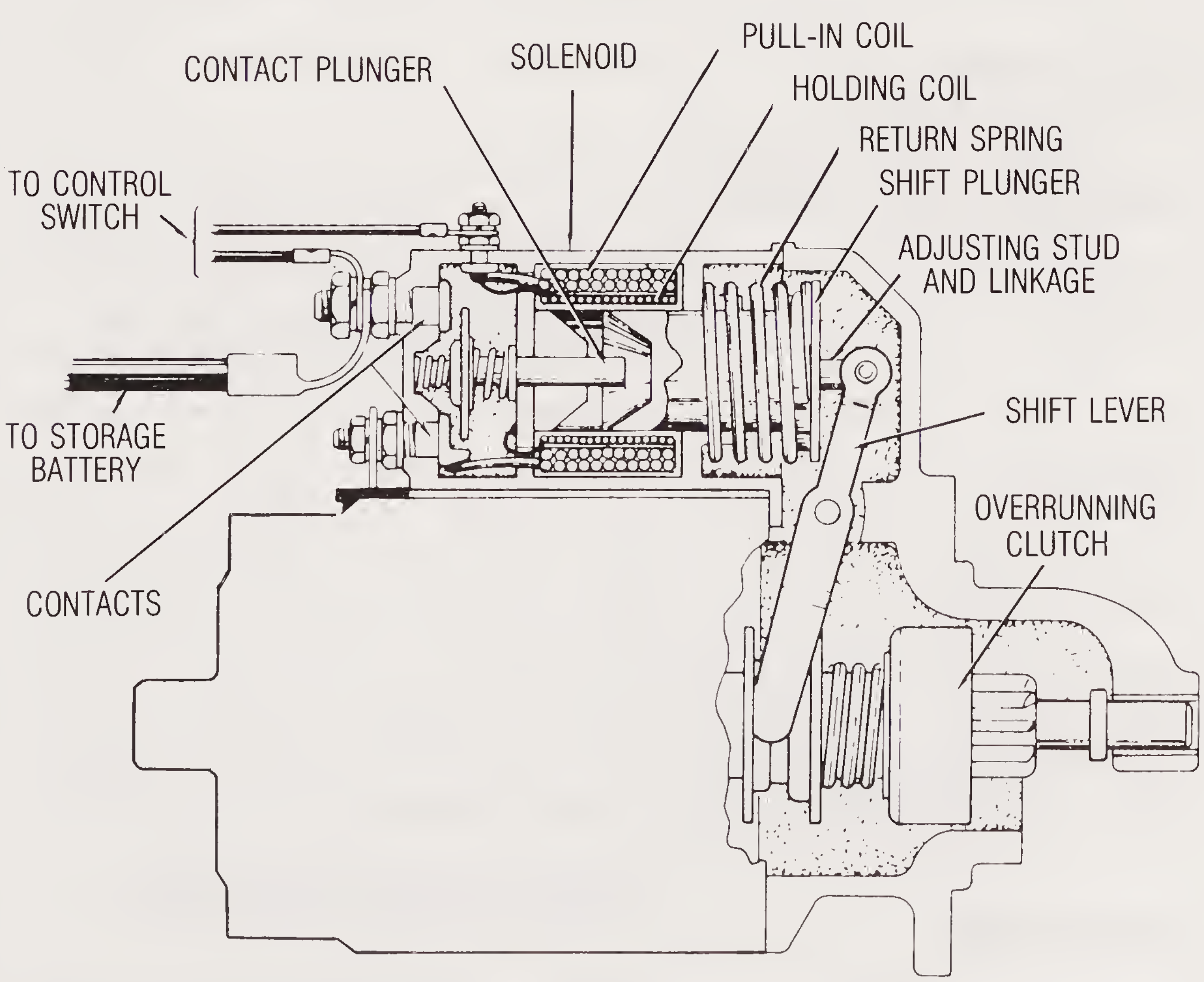



**Fig. 20-14. Arrangement of solenoid shift in clutch drive.**

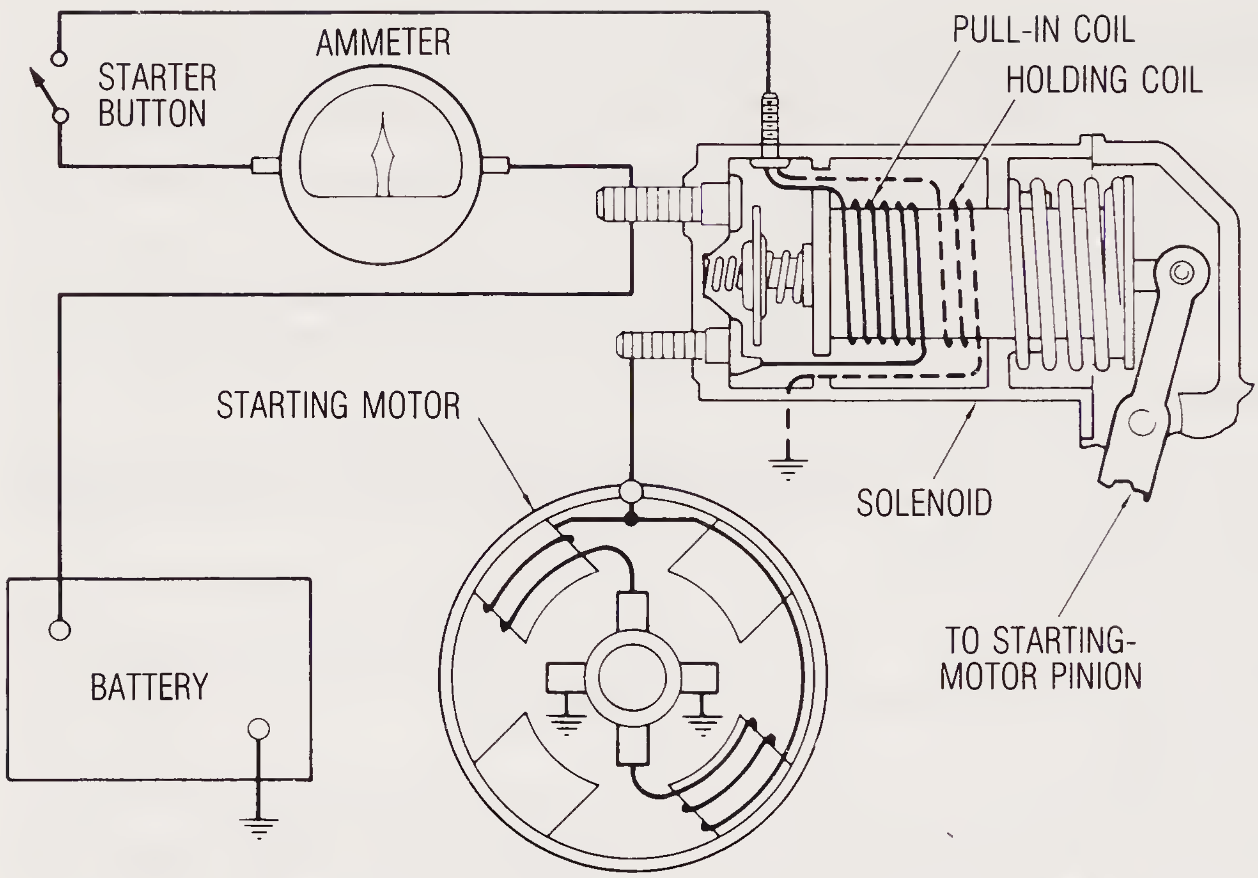



**Fig. 20-15. Schematic diagram showing solenoid wiring method.**

control circuit so that the current can be applied to the solenoid coil.

A relay is frequently used in the control circuit to supply current to the solenoid coil. Only a low-current control circuit to the instrument panel is then necessary. The relay will close the circuit through the solenoid coil which carries a larger current.

The most popular method of directly switching power to the starter relay, or solenoid, is of course the key-operated ignition switch. This very special switch utilizes a spring-loaded position at the extreme end of its movement to energize a separate set of starting contacts. The spring automatically returns the switch to the "on" ignition position immediately after the key is released. The entire ignition switch may be a single assembly or, as in many modern vehicles with steering-column-mounted ignition switches, may use a remote switch from the key tumbler assembly connected by a rod linkage. Such a system requires careful adjustment.

## Bendix Drive

Many industrial and older systems utilized the Bendix starting mechanism. This automatic screw pinion shift mechanism is designed in

two types: one is known as the *inboard type*, in which the pinion shifts toward the motor to disengage the flywheel; the other is an *outboard type*, in which the pinion shifts away from the motor. A typical assembly view of the outboard drive is shown in Fig. 20-16.

The same general construction, however, is used in both types. A sleeve having screw threads, with stops at each end to limit the lengthwise travel of the pinion, is mounted on the extended armature shaft. The pinion gear, which is unbalanced by the weight on one side, has corresponding internal threads for mounting on this sleeve. The sleeve is connected to the motor armature shaft through a special drive spring attached to a collar pinned to the armature shaft.

*In operation*, when the starting motor is not running, the pinion is out of mesh and entirely away from the flywheel gear. When the

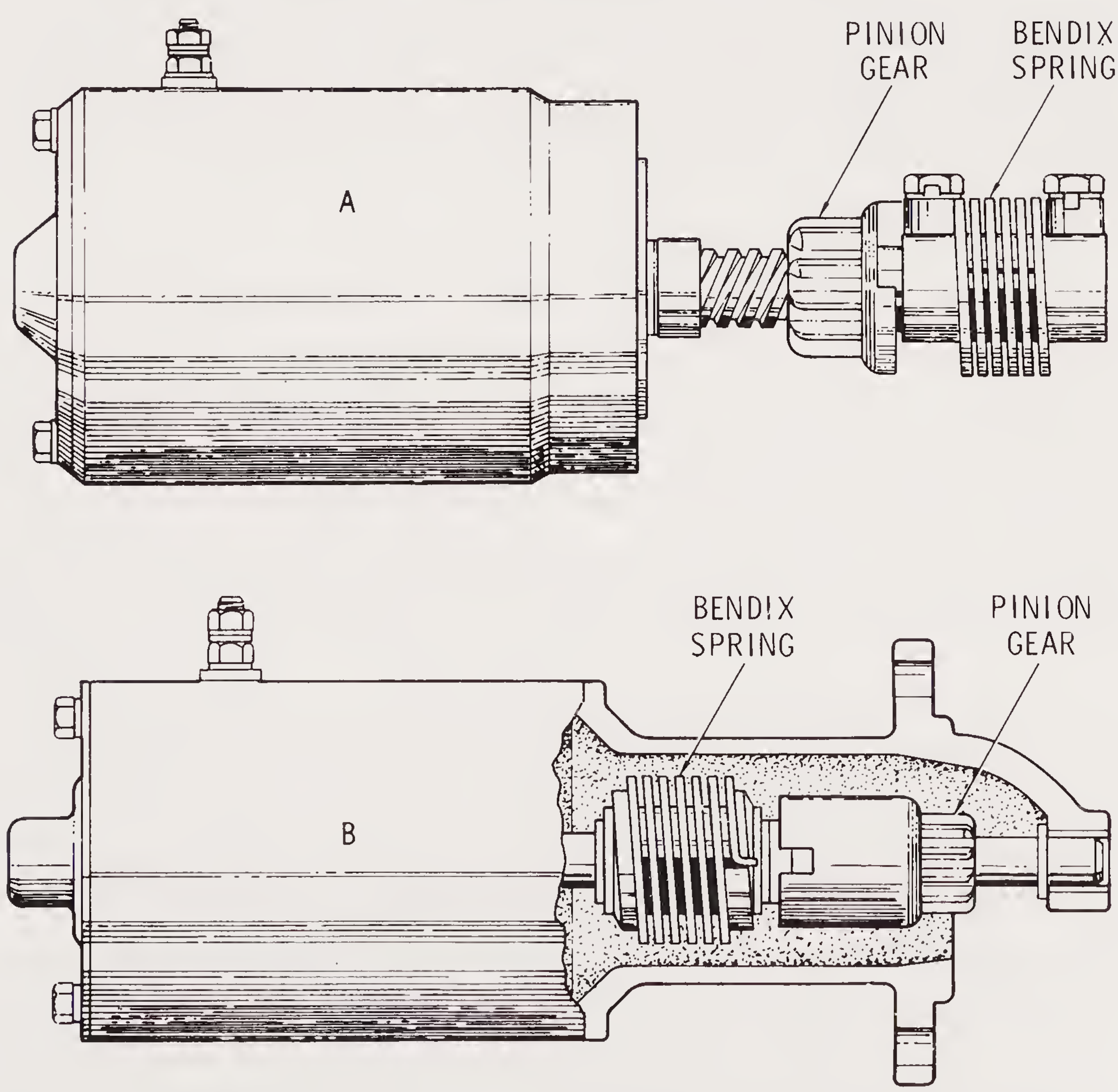



**Fig. 20-16. Bendix-drive starter showing gear arrangement. (A) Inboard type. (B) Outboard type.**

starting switch is closed and the battery voltage impressed on the motor, the armature starts to rotate at high speed. The pinion, being weighted on one side and having internal screw threads, does not rotate immediately with the shaft but, because of its inertia, runs forward on the revolving threaded sleeve until it meets and meshes with the flywheel gear.

If the teeth of the pinion and the flywheel meet instead of meshing, the drive spring allows the pinion to revolve and forces it into mesh with the flywheel. When the pinion gear is fully meshed with the flywheel gear, the pinion is then driven by the motor through the compressed drive spring and cranks the engine.

When the engine fires and runs on its own power, the flywheel drives the pinion at higher speed than does the starting motor, causing the pinion to turn in the opposite direction on the threaded sleeve and automatically demesh from the flywheel. This prevents the engine from driving the starting motor. When the pinion is automatically demeshed from the flywheel, it is held in a demeshed position by a latch until the starting switch is again closed.

## CHAPTER 21

# Troubleshooting

Because an internal combustion engine must perform the work of drawing in and compressing its charge before energy is developed in its cylinder, some special device is required to start it. To start an engine, therefore, requires the use of power from an external source. It is also necessary to disengage the load during the starting period.

Small engines as used on lawn mowers, outboard motors, etc., are usually started by starter cord, by turning the flywheel or by a special hand gear. The latter must have a ratchet or clutch which will release or throw it out of gear as soon as power is developed.

The electrical, or self-starting, system is usually employed on large engines, particularly those used in automotive service. This starting system consists of an electric motor that is mechanically connected to the engine shaft through a set of gears and electrically connected to a storage battery, which furnishes the current required for starting.

The battery is kept charged by a generator or alternator which is commonly driven by means of a set of pulleys and belts from the engine. The generator also assists the battery in supplying the current requirements for lights and ignition under normal operating conditions.

When an engine fails to start, the trouble in the majority of cases is to be found in the ignition system, a run-down battery, an open electrical circuit, the fuel system and other miscellaneous causes.

All internal combustion engines, whether two-, or four-stroke-cycle, depend for their proper performance upon a supply of correct fuel mixture, good compression and an adequate spark to ignite the mixture at the proper time.

Troubles and remedies in two-stroke-cycle engines are similar to those for the four-stroke-cycle automotive-type gasoline engines, the difference being mainly due to the method of getting the fuel-air mixture into the combustion chamber. In most small two-stroke-cycle engines, the fuel mixture passes through the crankcase and enters the combustion chamber through ports uncovered by the piston.

It should be distinctly understood that in this chapter the "Remedies" sections tell you *what to do*, not *how to do it*. To give service technique here would be a useless repetition of instructions given in other sections of the book.

## SERVICE DIAGNOSIS

### Conditions—Possible Causes—Remedies

1. **Engine will not start**

   Possible Common Causes:

   *a.* Weak battery.
   *b.* Corroded or loose battery terminal connections.
   *c.* Dirty or corroded distributor cap or rotor.
   *d.* Weak coil.
   *e.* Broken or loose ignition wires.
   *f.* Moisture on ignition wires, cap or plugs.
   *g.* Fouled spark plugs.
   *h.* Malfunctioning electronic ignition.

*i.* Improper timing (ignition).
*j.* Dirt or water in gas line or carburetor.
*k.* Carburetor flooded.
*l.* Fuel level in carburetor bowl not correct.
*m.* Supply of fuel insufficient.
*n.* Defective fuel pump.
*o.* Vapor lock.
*p.* Defective starting motor.
*q.* Open ignition switch circuit.
*r.* Inoperative breaker points.

Remedies:

*a.* Recharge and test battery. If necessary, replace battery.
*b.* Clean, inspect and tighten battery terminals and clamps. Replace battery cables and clamps if badly eroded.
*c.* Clean and inspect; if badly burned or pitted, replace cap or rotor. Check for carbon tracking between terminals.
*d.* Replace weak coil with a new one.
*e.* Replace broken ignition wires or those with cracked insulation. Tighten all connections at distributor, coil, ammeter and ignition switch. Be sure the spark plug wires are secure in distributor cap and coil tower.
*f.* Dry the wet ignition system with compressed air or a clean, dry cloth. Remove the individual spark plug wire from cap; dry cavity and wire ends thoroughly. Inspect inside of cap and remove all traces of moisture and dirt.
*g.* Clean and tighten spark plugs. Adjust gaps to manufacturer's specifications.
*h.* Check electronic ignition system by manufacturer's procedure and replace bad components.
*i.* Check ignition timing. Adjust to manufacturer's specifications.
*j.* Disconnect fuel lines and clear with compressed air. Remove and clean carburetor. Drain tank and refill.
*k.* Check carburetor float level and needle seat assembly. Check float for leaks and replace parts as necessary to correct this condition.
*l.* Check carburetor for dirt, varnish or gumming; disassemble and clean.

*m.* Set float level to manufacturer's specifications.
*n.* Replace defective fuel pump with a new one to correct this condition.
*o.* Check for air and fuel restrictions around fuel pump and check for a misplacement of heat shield. Repair as necessary to correct this condition.
*p.* Repair or replace defective starting motor. Replace worn or damaged parts as required.
*q.* Turn ignition switch on; if ammeter shows a slight discharge, it indicates that current is flowing. A glance at the fuel guage will indicate whether or not there is fuel in the tank. If no indication is obtained when turning the ignition switch on, the circuit is faulty and should be repaired.
*r.* Inspect operation and condition; clean or replace as necessary. Set to manufacturer's specifications.

**2. Engine stalls**

Possible Causes:
*a.* Idling speed too low.
*b.* Idle mixture too lean or too rich.
*c.* Dirt or water in gas line or carburetor.
*d.* Incorrect carburetor float level.
*e.* Leak in intake manifold vacuum.
*f.* Defective accelerator pump (stall occurs on acceleration).
*g.* Improper choke adjustment (stalls before warm-up).
*h.* Carburetor icing (cold wet weather).
*i.* Weak fuel pump.
*j.* Fuel system emission controls malfunction.
*k.* Weak battery and charging system.
*l.* Spark plugs dirty, or gaps incorrectly set or worn.
*m.* Coil defective, with low output.
*n.* Distributor cap and rotor burned, worn or tracked.
*o.* Improper ignition timing.
*p.* Leaks in ignition wiring.
*q.* Burned or pitted valves.
*r.* Engine overheating.

Remedies:
*a.* Reset throttle adjustment screw until engine idles at manufacturer's specifications.

*b.* Reset idle adjustment screw for correct idle mixture. For richer mixture, turn screw out.
*c.* Disconnect lines and clear with compressed air. Remove and clean carburetor.
*d.* Fuel level should be adjusted to manufacturer's specifications.
*e.* Check intake manifold, gasket and vacuum hoses. Replace parts as required to correct this condition.
*f.* Replace or repair defective accelerator pump. Replace parts as required.
*g.* Readjust automatic choke.
*h.* Open throttle as engine starts to stall. Keep motor at fast idle until condition clears. Check heat riser valve and passages.
*i.* Check fuel pump pressure at carburetor and replace if necessary.
*j.* Check vapor emission systems as to manufacturer's specifications.
*k.* Recharge and test battery and charging system. If necessary, replace any defective part with a new one of the same type and capacity.
*l.* Clean or replace spark plugs. Adjust plug gaps to manufacturer's specifications.
*m.* Replace defective coil.
*n.* Replace distributor cap and rotor.
*o.* Set ignition timing to manufacturer's specification.
*p.* Replace broken ignition wires or those with cracked insulation. Tighten all connections at coil and distributor. Be sure the spark plug wires are secure in distributor cap and coil tower.
*q.* Replace or reface and grind valves.
*r.* Refer to Chapter 12, "Cooling Systems," for various causes of engine overheating. Correct as indicated.

**3. Engine has no power**

Possible Causes:

*a.* Incorrect ignition timing.
*b.* Coil has low output.
*c.* Electronic ignition malfunctioning.

*d.* Defective mechanical or vacuum advance (distributor).
*e.* Emission controls malfunctioning.
*f.* Worn or misadjusted points.
*g.* Spark plugs dirty or worn.
*h.* Poor fuel used.
*i.* Carburetor in poor condition.
*j.* Dirt or water in gas line or carburetor.
*k.* Partially plugged fuel filter.
*l.* Defective fuel pump.
*m.* Valve timing incorrect.
*n.* Malfunctioning fuel injection.
*o.* Low compression.
*p.* Plugged or restricted exhaust system.
*q.* Clutch slipping.
*r.* Engine overheating.

Remedies:
*a.* Check and reset ignition timing. Replace parts as necessary to correct this condition.
*b.* Replace defective coil.
*c.* Check electronic ignition system by manufacturer's procedure and replace bad components.
*d.* Check vacuum-advance mechanism. Make adjustments or replace parts as necessary to correct this condition.
*e.* Check EGR system and gas tank venting components and set to manufacturer's specifications.
*f.* Install and adjust new points.
*g.* Clean or replace spark plugs. Adjust plug gaps.
*h.* Drain fuel tank and refill with a clean fresh fuel.
*i.* Remove and recondition carburetor. Replace parts as required to correct this condition.
*j.* Disconnect lines and clear with compressed air. Remove and clean carburetor. Drain tank and refill.
*k.* Replace fuel filter.
*l.* Replace defective fuel pump with a new one to correct this condition.
*m.* Replace timing chain or belt, reset valve timing to manufacturer's specifications.

*n.* Check fuel injection by manufacturer's procedure and replace bad components.
*o.* Replace or reface and grind valves. Replace piston rings.
*p.* Remove plugged or restricted muffler, catalytic converter or pipe and replace with a new one. Check for excessive carbon in combustion chamber.
*q.* Refer to Chapter 19 for possible causes and remedies. Correct as indicated.
*r.* Refer to Chapter 12 for possible causes and remedies. Correct as indicated.

**4. Engine "skips" or misses at idle or low speeds**

Possible Causes:
*a.* Spark plugs dirty, damp, or worn.
*b.* Moisture on ignition wires, cap or plugs.
*c.* Leaks in ignition wiring.
*d.* Incorrect carburetor idle adjustment.
*e.* Dirt or water in gas line or carburetor.
*f.* Incorrect ignition timing.
*g.* Dirty jets or plugged passages in carburetor idle or main circuit.
*h.* Excessive wear in distributor cap or rotor.
*i.* Defective electronic ignition pickup.
*j.* Defective electronic ignition control unit.
*k.* Burned, warped or pitted valves.
*l.* Malfunctioning fuel injection system.

Remedies:
*a.* Clean or replace spark plugs. Adjust plug gaps to manufacturer's specifications.
*b.* Dry the wet ignition system with compressed air or a clean, dry cloth. Remove the individual spark plug wires from cap; dry cavity and wire ends thoroughly. Inspect inside of cap and remove all traces of moisture and dirt.
*c.* Replace broken ignition wires or those with cracked insulation. Tighten all connections at distributor and ignition coil. Be sure the spark plug wires are secure in distributor cap and coil tower.

*d.* Reset idle adjustment screw for correct idle mixture.
*e.* Disconnect lines and clear with compressed air. Remove and clean carburetor. Drain tank and refill.
*f.* Check and reset ignition timing.
*g.* Remove carburetor and recondition. Replace parts as necessary to correct this conditon.
*h.* Check distributor shaft play. Replace parts as required to correct this condition.
*i.* Test pickup according to manufacturer's specifications and replace as necessary.
*j.* Test control unit according to manufacturer's procedure and replace if necessary.
*k.* Replace, or reface and grind valves.
*l.* Check fuel injection system according to manufacturer's procedure and replace defective parts.

**5. Engine misses on acceleration**

Possible Causes:

*a.* Distributor points worn or incorrectly spaced.
*b.* Coil defective.
*c.* Incorrect ignition timing.
*d.* Spark plugs dirty, damp, or worn.
*e.* Poor ignition wires.
*f.* Dirty jets in carburetor, especially enrichment circuit; or accelerator pump operating improperly.
*g.* Fuel injection malfunctioning.
*h.* Defective electronic ignition component.

Remedies:

*a.* Clean and inspect contact points; if badly burned or pitted, replace points and condenser. Adjust point gap to manufacturer's specifications and then check timing.
*b.* Replace defective coil.
*c.* Check and reset ignition timing.
*d.* Clean or replace spark plugs. Adjust plug gaps to manufacturer's specifications.
*e.* Replace faulty ignition wires.

*f.* Remove carburetor and recondition. Replace parts as required to correct this condition.
*g.* Test fuel injection according to manufacturer's procedure and replace necessary components.
*h.* Test electronic injection according to manufacturer's procedure and replace necessary components.

**6. Engine misses at high speed**

Possible Causes:

*a.* Dirt or water in gas line or carburetor.
*b.* Dirty jets or enrichment circuit in carburetor.
*c.* Coil defective.
*d.* Incorrect ignition timing.
*e.* Distributor points worn or incorrectly set.
*f.* Rotor or cap severely worn.
*g.* Loose or bad ignition wires.
*h.* Defective electronic ignition pickup.
*i.* Spark plugs dirty, damp or worn.
*j.* Defective electronic ignition control unit.
*k.* Defective fuel injection.

Remedies:

*a.* Disconnect lines and clear with compressed air. Remove and clean carburetor. Drain tank and refill.
*b.* Remove carburetor and recondition. Replace parts as necessary to correct this condition.
*c.* Replace defective coil.
*d.* Check and reset ignition timing.
*e.* Clean and inspect contact points; if badly burned or pitted, replace points and condenser. Adjust point gap to manufacturer's specifications and then check timing.
*f.* Replace worn rotor with a new one. Check contacts in cap for burning or pitting. If necessary, replace distributor cap.
*g.* Replace broken ignition wires or those with cracked insulation. Tighten all connections and be sure the spark plug wires are secure in distributor cap.
*h.* Test pickup according to manufacturer's specifications and replace as necessary.

*i.* Clean or replace spark plugs. Adjust plug gaps to manufacturer's specifications.
*j.* Test according to manufacturer's specifications and replace if necessary.
*k.* Test according to mannufactuer's specifications and replace defective componets.

## HIGH OIL CONSUMPTION

**7. External oil leakage**

Possible Causes:

*a.* Tappet or valve cover gaskets.
*b.* Oil filter gasket.
*c.* Oil pan drain plug.
*d.* Fuel pump or gasket.
*e.* Oil pressure sending unit.
*f.* Oil pan gaskets.
*g.* Rear main bearing oil seal.
*h.* Timing gear case cover oil seal.
*i.* Intake manifold (V type).
*j.* Timing chain cover gasket.
*k.* Outside oil lines.

Remedies:

*a.* Remove gaskets from tappet or valve covers and replace with new ones. Before installing, be sure all traces of old gasket have been removed from the machined faces of block. Wipe surfaces dry and install covers. Always open drain holes.
*b.* Clean filter and cover, removing all traces of old gasket. Install new gasket, using care to be sure gasket is centered. Make hand tight only, then run engine for five minutes; inspect for leakage.
*c.* Replace worn oil pan plug, using a new gasket.
*d.* Replace fuel pump or gasket. Check fuel pump for oil leaks after installing.

*e.* Clean off sending unit and run for 10 minutes; inspect for leaks; replace if necessary.
*f.* Replace faulty oil pan gaskets to correct this condition.
*g.* Replace rear main bearing oil seal. Be sure seal and gaskets are in correct location in the cap before installation.
*h.* Replace chain case cover oil seal. Be sure to use a new cover gasket. Check seal surface of balancer or shaft for wear.
*i.* Remove intake manifold and check drain hole. Check and clean gasket surface; install with new gaskets.
*j.* Replace timing chain cover gasket. Inspect oil seal and if necessary, replace.
*k.* Check for oil leaks at filter tubes and oil gauge lines. Replace tubing or fittings to correct this condition. Be sure filter mounting bracket is fastened tightly.

**8. Oil pumping at rings**

Possible Causes:
*a.* Worn or broken rings.
*b.* Incorrect size rings.
*c.* Out-of-round cylinders.
*d.* Rings stuck in grooves.
*e.* Carbon in oil drain holes or slots.
*f.* Insufficient tension in rings.
*g.* Excessive rod bearing clearance causing excessive oil to be splashed on cylinder walls.

Remedies:
*a.* Replace worn rings after a careful inspection of cylinder walls. Worn, wavy or scored walls are a contributing factor to high oil consumption. Recondition cylinder walls.
*b.* Replace incorrect size rings with new piston rings of the proper type.
*c.* Rebore out-of-round cylinders after checking cylinder bore.
*d.* Replace frozen or stuck rings with new piston rings. Check oil ring clearance in groove.
*e.* Remove rings and clean piston ring slots with a suitable cleaning tool. Check cylinder bore and rings.

*f.* Replace weak rings with new rings after checking condition of cylinder walls.
*g.* Measure rod bearing clearances and replace if necessary.

**9. Oil pumping at valves**

Possible Causes:

*a.* Worn or heat-damaged valve seals.
*b.* Plugged oil return drain holes.
*c.* Worn valve stems or guides.

Remedies:

*a.* Replace worn or damaged seals whenever this condition is apparent.
*b.* Remove valve or tappet covers; open drain holes.
*c.* Replace worn valves and guides as necessary to correct this condition.

**10. High oil consumption due to lubricating oil**

Possible Causes:

*a.* Oil level too high.
*b.* Water-contaminated oil.
*c.* Poor grade of oil.
*d.* Thin, diluted oil.
*e.* Oil pressure too high.
*f.* Sludge in engine blocking return drain holes.

Remedies:

*a.* Add oil only when level reaches add oil mark. If oil level is over "full," drain sufficient oil to obtain correct level.
*b.* Drain and refill crankcase with a good-quality oil of the proper type and grade. Replace filter cartridge or filter.
*c.* Drain and refill crankcase with a good-quality oil of manufacturer's specified weight. Replace filter cartridge or filter.
*d.* Drain and refill crankcase with a good-quality oil. Replace filter cartridge or filter. Check operation of automatic choke and carburetor for source of fuel.
*e.* Free up sticking relief valve or replace oil pressure relief valve spring.

*f.* Drain and refill crankcase with a good-quality oil. Replace filter cartridge or filter after thoroughly cleaning all return drain holes under valve or tappet covers and intake manifold. Check thermostat. A thermostat that remains in the open position allows the engine to operate below normal temperatures, thus allowing sludge formation. Also check PCV valve and breather system.

**11. High oil consumption—miscellaneous**

Possible Causes:

*a.* Overheating engine.
*b.* Sustained high speeds.
*c.* Plugged breather cap causing excessive crankcase ventilation vacuum.
*d.* Plugged PCV system causing crankcase pressure.

Remedies:

*a.* Refer to the Chapter 12 for correction of this condition.
*b.* Avoid sustained high speeds at wide-open throttle whenever possible or change to heavier-weight oil.
*c.* Check breather. Inspect crankcase ventilator outlet tube and oil drain passage in block for restrictions. Clean or repair as required to correct this condition.
*d.* Replace PCV valve and open all passages and hoses.

## ENGINE NOISES

**12. Piston noise**

Possible Causes:

*a.* Piston pin fit too tight or too loose.
*b.* Excessive piston-to-bore clearance.
*c.* Collapsed piston skirt.
*d.* Insufficient clearance to cylinder head due to carbon buildup.
*e.* Broken piston or skirt.

Remedies:

*a.* Refit piston pins as required.

*b.* Replace pistons as required. Check cylinder walls for excessive wear; if necessary, recondition cylinder walls and install new pistons to fit manufacturer's specifications.
*c.* Replace pistons as required. Check cylinder walls for possible scoring; recondition as necessary to correct.
*d.* Remove cylinder head and clean carbon from chamber, pistons, and valves.
*e.* Replace pistons as required. Check cylinder walls for possible scoring or damage. Recondition walls if necessary and install new pistons.

**13. Valve noise**

Possible Causes:
*a.* Excessive valve clearance.
*b.* Worn or stuck hydraulic valve lifters.
*c.* Gum formation on stem causing valves to stick.
*d.* Weak valve springs.
*e.* Worn camshaft.

Remedies:
*a.* Check and adjust valves with engine at normal operating temperature.
*b.* Replace hydraulic lifters. Check camshaft for pitting and wear.
*c.* Remove gum from valve stems, grind, reinstall and adjust. Replace valves, if necessary.
*d.* Valve springs can be checked with testing gauge.
*e.* Replace worn camshaft and always install new lifters.

**14. Connecting rod noise**

Possible Causes:
*a.* Low oil pressure.
*b.* Insufficient oil supply (splash lubrication system).
*c.* Thin or diluted oil.
*d.* Misaligned rods.
*e.* Excessive bearing clearance.
*f.* Eccentric or out-of-round crank pin journal.

Remedies:

*a.* Refer to Chapter 11 for possible causes of low oil pressure. Correct as indicated. Check oil pump thoroughly.

*b.* Check oil level in crankcase; if necessary, add oil to obtain correct level, or drain and refill. Test for possible loose or damaged rod bearings.

*c.* Drain and refill crankcase and then test for possible loose or damaged rod bearings.

*d.* Check rods for alignment; if necessary, straighten rod or install new one to correct this condition. Check bearing and journal for excessive wear. Replace parts as required.

*e.* Replace worn bearings as required. Fit connecting rod bearings to manufacturer's clearance.

*f.* Replace or regrind crankshaft as necessary. Replace with new fitted undersize bearings after grinding operation is completed.

**15. Main bearing noise**

Possible Causes:

*a.* Low oil pressure.

*b.* Insufficient oil supply (splash lubrication system).

*c.* Thin or diluted oil.

*d.* Excessive bearing clearance.

*e.* Excessive end play or thrust bearing.

*f.* Eccentric or out-of-round journals.

Remedies:

*a.* Refer to Chapter 11 for possible causes of low oil pressure. Correct as indicated. Check pump thoroughly.

*b.* Check oil level in crankcase; if necessary, add oil to obtain correct level, or drain and refill. Test for possible loose or damaged main bearings.

*c.* Drain and refill crankcase; then test for possible loose or damaged main bearings.

*d.* Replace worn bearings as required. Fit main bearings to manufacturer's clearance.

*e.* Replace thrust bearing; measure and replace crankshaft if necessary.

*f.* Replace crankshaft or regrind journals as necessary. Replace with new fitted undersize bearings when grinding operation is completed.

**16. Broken piston rings**

Possible Causes:

*a.* Wrong type or size.
*b.* Worn pistons (excessive clearance).
*c.* Ring striking top ridge.
*d.* Worn ring grooves.
*e.* Broken ring lands.
*f.* Insufficient end gap clearance.
*g.* Excessive side clearance in groove.
*h.* Uneven cylinder walls (particularly due to a previous ring wear in same cylinder).

Remedies:

*a.* Replace rings as required, after checking cylinder walls for possible scoring or grooving. When replacing rings, use only those that are factory engineered and inspected and the correct type and size for the engine being worked on.
*b.* Fit new pistons and rings. Rebore or sleeve cylinders.
*c.* Replace rings as required, after checking cylinder walls for possible scoring or grooving. Remove ridge and recondition walls, if necessary.
*d.* Replace pistons and rings, after checking cylinder walls for possible scoring or grooving. Recondition cylinder walls as required.
*e.* Replace pistons and rings as required, after checking cylinder walls for possible scoring or grooving. Recondition cylinder walls if necessary.
*f.* Replace rings as required. Check walls for damage and recondition if necessary. Correct ring gap to manufacturer's specifications.
*g.* Replace pistons as required. Inspect cylinder walls for damage and recondition if necessary.
*h.* Fit new pistons and rings, after reboring or sleeving cylinder walls.

**17. Broken pistons**

Possible Causes:

*a.* Undersize pistons (excessive clearance).
*b.* Eccentric or tapered cylinders.
*c.* Misaligned connecting rods.
*d.* Engine overheating.
*e.* Excessive engine speed or loading at low rpm.
*f.* Water or fuel leakage into combustion chamber.
*g.* Detonation or preignition.

Remedies:

*a.* Recondition cylinder walls and fit oversize pistons.
*b.* Recondition cylinder walls and fit new pistons and rings.
*c.* Recondition cylinder walls if necessary; then fit new pistons and rings. Realign connecting rods.
*d.* Recondition cylinder walls if necessary; then fit new pistons and rings. Refer to Chapter 12 for possible causes and remedies of engine overheating.
*e.* Recondition cylinder walls if necessary; then fit new pistons and rings. Avoid the practice of "racing" or "lugging" the engine.
*f.* Recondition cylinder walls if necessary; then fit new pistons and rings. Check cylinder head, gasket and cylinder block for leaks. Repair as necessary to correct this condition.
*g.* Recondition cylinder walls if necessary; then fit new pistons and rings. Check for excessive spark advance and insufficient octane fuel.

**18. Low oil pressure**

Possible Causes:

*a.* Thin or diluted oil.
*b.* Oil relief valve spring broken or weak; oil pressure relief valve sticking.
*c.* Restricted oil pump screen.
*d.* Excessive clearance in main or connecting rod bearings.
*e.* Excessive clearance in camshaft bearings.
*f.* Low oil level.

*g.* Loose connections or restricted oil lines.
*h.* Worn oil pump.

Remedies:

*a.* Drain, flush and refill crankcase.
*b.* Replace broken or weak relief spring, clean relief valve and bore.
*c.* Remove strainer, disassemble and wash in solvent or replace. Clear with an air hose and install.
*d.* and *e.* Check clearance in main, connecting rod and camshaft bearings. Correct as necessary.
*f.* Add oil to bring capacity up to the proper level. Check for bearing damage.
*g.* Check for restricted lines and clean out or replace where necessary. Check for leaking connecting lines.
*h.* Check pump according to manufacturer's procedure and specifications. Rebuild or replace as necessary.

CHAPTER 22

# Engine Tune-Up

The term *tune-up* as applied to a gas engine is defined as *the testing and servicing of the engine's various mechanisms upon whose proper functioning satisfactory and efficient operation of the engine depends.* These various mechanisms are the *starting, ignition, carburetor* and *cooling* systems in addition to the *valves* and *valve gears.*

There are two kinds of tune-up, termed *minor* and *major.* A minor tune-up is confined principally to the ignition system, whereas a major tune-up comprises a complete engine diagnosis or overall check and servicing where necessary.

## MINOR ENGINE TUNE-UP

A minor engine tune-up is intended as a preventive measure for engines that are in fairly normal condition. This tune-up should be

performed frequently in order to maintain the standard performance originally built into the engine. If the engine does not perform satisfactorily after a minor tune-up, a major tune-up including a compression test may be necessary.

A minor tune-up includes tests and servicing of:

1. Battery—check and add water.
2. Spark plugs—usually replace.
3. Distributor—check and adjust.
4. Magneto (when used).
5. Wiring circuits—check.
6. Ignition timing—check and adjust.
7. Carburetion—check and adjust.
8. Fuel and air filters.

## Battery

Inspect the battery cable and ground strap for broken insulation, corroded or broken strands and loose or corroded terminals. Repair broken or chafed insulation with loom or tape. If cable strands are broken, corroded, or loose in the terminals, the cables should be replaced with new cable of adequate current-carrying capacity.

Clean and tighten all connections. Test for weak or discharged battery. Make a voltage test of the battery cells. Add water if necessary. Tighten all primary and high-tension wire connections, particularly at the ignition starter switch, ammeter and fuel gauge behind the instruments.

## Spark Plugs

Probably more fuel is wasted by faulty spark plugs than from any other cause. Such alleged tests as the screwdriver test or laying the plug on top of the cylinder indicate nothing except that the plug is absolutely dead; and while a faulty plug may spark on very low compression, it will cease sparking with increasing compression, as when a load is put on the engine. Most gas and service stations have ignition analyzers to indicate conditions of the plugs.

## Reasons Spark Plugs Fail

| Plug Condition | Cause |
|---|---|
| *a.* Fouled with oily carbon. | Excessive oil consumption. |
| *b.* Fouled with brown crusty carbon. | Excessive oil consumption. |
| *c.* Black fouled; dry. | Rich fuel mixture (carburetor, air cleaner or choke at fault). |
| *d.* Metallic specks on damaged insulator. | Excessive spark advance or low-octane fuel. |
| *e.* Cracked but very clean insulator. | Excessive engine temperature or lean fuel mixture (excessive high-speed engine operation). |
| *f.* Electrode shows signs of melting—extreme side electrode erosion; very clean insulator. | Excessive engine temperature or lean fuel mixture (excessive high-speed engine operation). |
| *g.* Physical damage to plug. | Mechanical failure in engine or foreign material passing through engine. |
| *h.* Rounded electrode and excessive gap; relatively clean insulator. | Normal wear. |

Carefully inspect the insulators and electrodes of all spark plugs. Replace any plug that has a cracked or broken insulator or loose electrodes. If the insulator is worn away around the center electrode, or if the electrodes are burned or rounded, the plug is worn out and should be replaced.

## Distributor

Adjust breaker points or electronic pickup. Inspect distributor cap and rotor for cracks and corrosion. Inspect small lead wires for breaks and damaged insulation. Inspect distributor advance plate for excessive play.

Every tune-up must include a complete distributor test. The

testing should be done in accordance with the testing equipment manufacturer's instructions and recommendations, giving necessary attention to all parts of the distributor.

## Condenser Test.

An open-circuited condenser will cause ignition trouble. Trouble of this nature is usually caused by a broken lead, bad connections inside the condenser or a poor ground connection. A condenser can always be checked. Charge the condenser from a battery, then touch the condenser lead to the condenser shell to see if spark occurs. See Figs. 22-1 and 22-2.

One of the best methods of testing a condenser is with an ohmmeter. When the ohmmeter is first connected to the condenser, the resistance should read low, then rebound back to high. After a few seconds the ohmmeter should again read extremely high resistance. Reversing the leads of the meter should cause the same meter reaction, only stronger. If the meter never moves from high

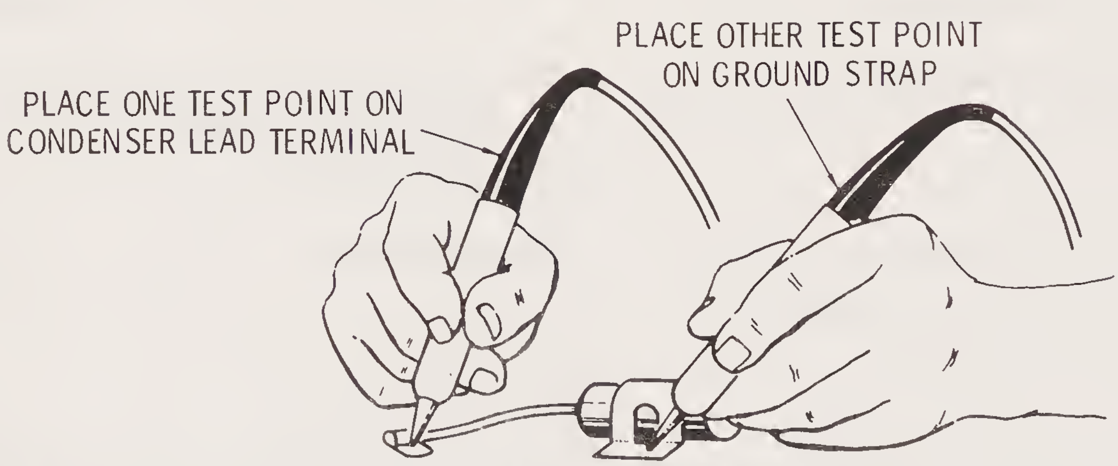



**Fig. 22-1. Testing condenser for short circuit. The test lamp will light if the condenser is short-circuited.**

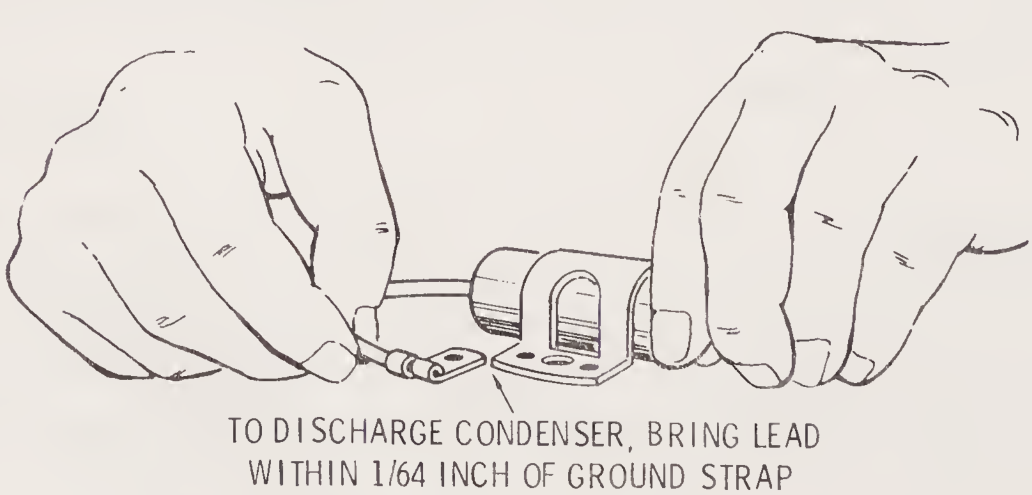



**Fig. 22-2. Testing a condenser for open circuit.**

resistance or displays a constant low resistance reading, the condenser is defective and must be replaced.

## Capacity Requirements.

It has been found that a lower-capacity condenser is suitable for continuous high-speed operation, while a higher-capacity condenser is suitable for continuous low-speed operation.

The capacity of a condenser used to satisfy average operating conditions is .20–.25 microfarads. Condensers in automotive use are in the .15–.45-microfarads capacity range. Fig. 22-3 shows pitted contact points caused by using a condenser with incorrect capacity for normal operating conditions.

## High-Tension Distributor Switch.

This comprises a distributor cap and rotor forming a rotary switch, which ordinarily has as many contacts as there are engine cylinders.

The rotor connects a central contact to each of these contacts in turn, and from there the current follows a secondary cable to the spark plug. These secondary cables are connected to the various spark plugs according to the firing order of the engine.

## Distributor Cap and Rotor Troubles.

Distributor caps and rotors are made of high-resistance plastic and very often a dirty tract is formed inside the cap where the rotor contact travels. This should be wiped clean; if the insulation of the cap is burned to any extent, the cap should be replaced with a new one.

When replacing either the distributor cap or the rotor, care

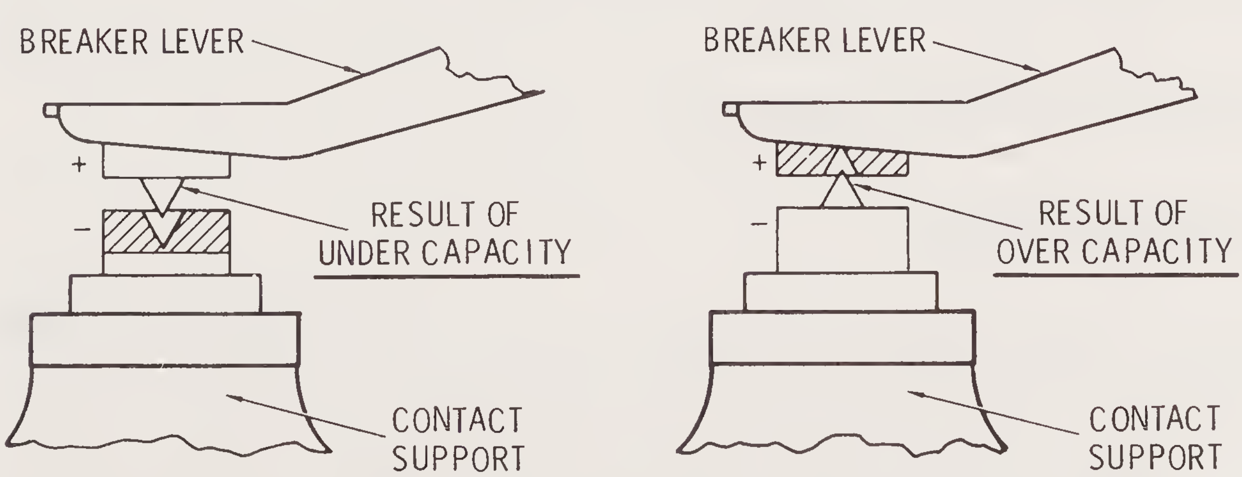



**Fig. 22-3. Pitting of breaker contacts due to condenser of wrong capacity.**

must be taken to use the proper replacement; otherwise they may not fit and align correctly, which would result in rapid burning of the new parts and poor performance of the engine.

## Magnetos

In most small engines, the magneto may become the cause of trouble. Although magnetos have so-called permanent magnets, sometimes, due to abuse or carelessness such as dropping the magnet rotor, most of the magnetism may be lost, thus making remagnetizing necessary.

To remagnetize a magnet rotor, proceed as follows:

1. Remove magnet motor from magneto.
2. Determine polarity of both magnet rotor and magnetizer by means of compass.
3. Place magnet rotor between jaws on tester as noted in Fig. 22-4. Note that unlike poles of both the magnet rotor and magnetizer must be placed together; that is, the jaw at the north pole end of the magnet rotor must rest on top of the south pole of the magnetizer.
4. With magnetizer properly connected to switch, allow current from batteries to flow through magnet rotor for about 5 seconds, disconnect current for about 3 seconds. Repeat the foregoing procedure three or four times.

After disassembly of magneto, all metal parts should be thoroughly cleaned in gasoline and dried with compressed air. All parts should be inspected for damage or wear.

The breaker contacts should be adjusted for an opening as specified by the manufacturer.

## Wiring Circuits

The circuits and parts that should be tested and replaced if necessary are:

1. Starting circuit.
2. Ignition circuit.

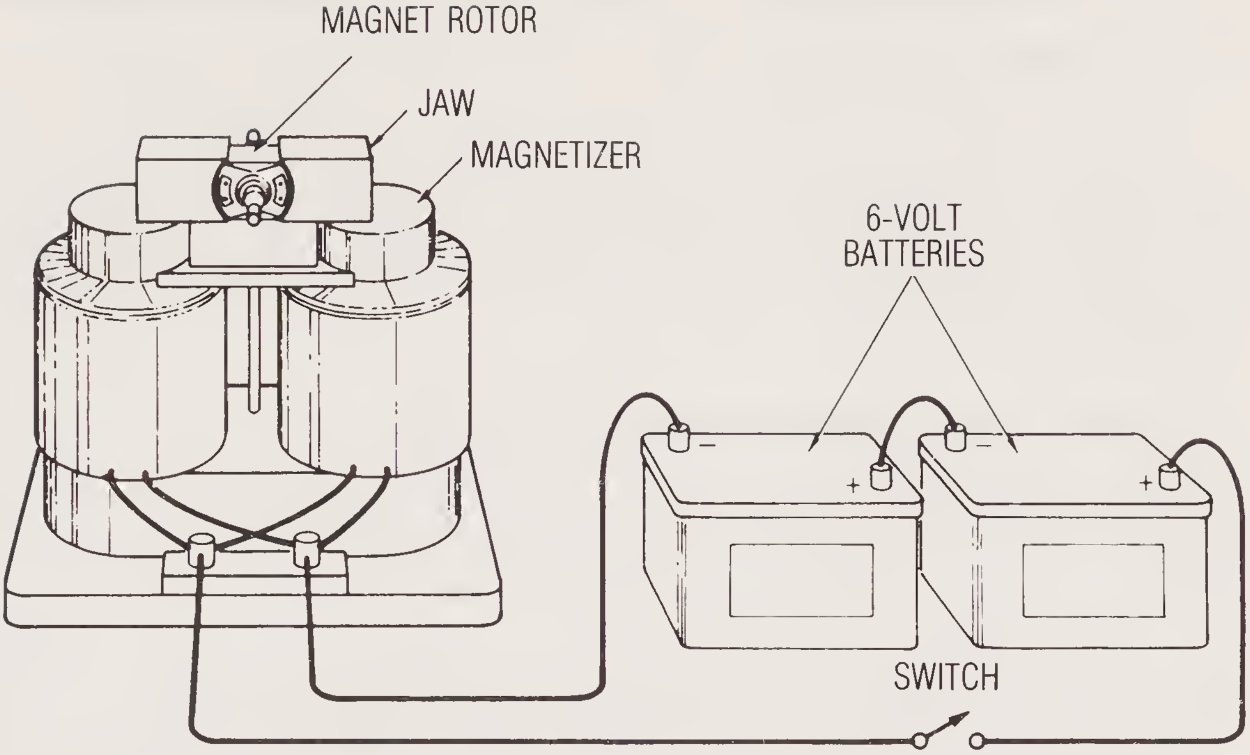



**Fig. 22-4. Typical magnet rotor remagnetizer.**

## Starting Circuit Test.

When testing the starting circuit, a voltmeter should be used to determine its condition under actual operating conditions.

Attach the negative voltmeter test lead to the engine for the ground connection, and the positive lead to the starting motor switch, where the cable from the battery fastens for the positive connection. (This connection is used when the negative post of the battery is grounded; reverse the connection if the opposite is true.)

By cranking the engine with the starter, a discharge load will be put on the starter circuit. If the starter turns the engine at a good rate of speed, the average voltage reading should be above 10 volts for 12-volt circuits.

For satisfactory circuits the starter should crank engine for 15 seconds without any perceptible voltage drop because of the drain on the battery. Such performance indicates a satisfactory circuit.

## Battery Cable Test.

Connect positive voltmeter test lead to the positive battery post, and the negative test lead to the battery cable terminal on the starter switch. Crank the engine for 15 seconds while observing the voltmeter reading. If the voltmeter shows more than 0.2 volts drop,

recheck loose and dirty terminals. If the terminals are tight and clean, replace the cable.

The battery ground cable test is shown in Fig. 22-5. This test is made in the same manner as the battery cable test, except that the negative voltmeter lead should be connected to the engine frame, and the positive voltmeter lead should be connected to the negative battery post.

## Generator and Starter Circuit Tests.

Whenever the starter, generator or voltage regulator require servicing, the wiring circuit should be checked for loose or defective connections and frayed or damaged wires.

High resistance is frequently the underlying cause of many electrical difficulties that cannot be permanently repaired until the cause is located and corrected. To check for resistance (voltage drop) in the starter and generator circuits, the following equipment is required:

1. An accurately calibrated voltmeter with a 10-volt scale graduated in 0.1-volt divisions or a millivolt meter of 500-mV range.

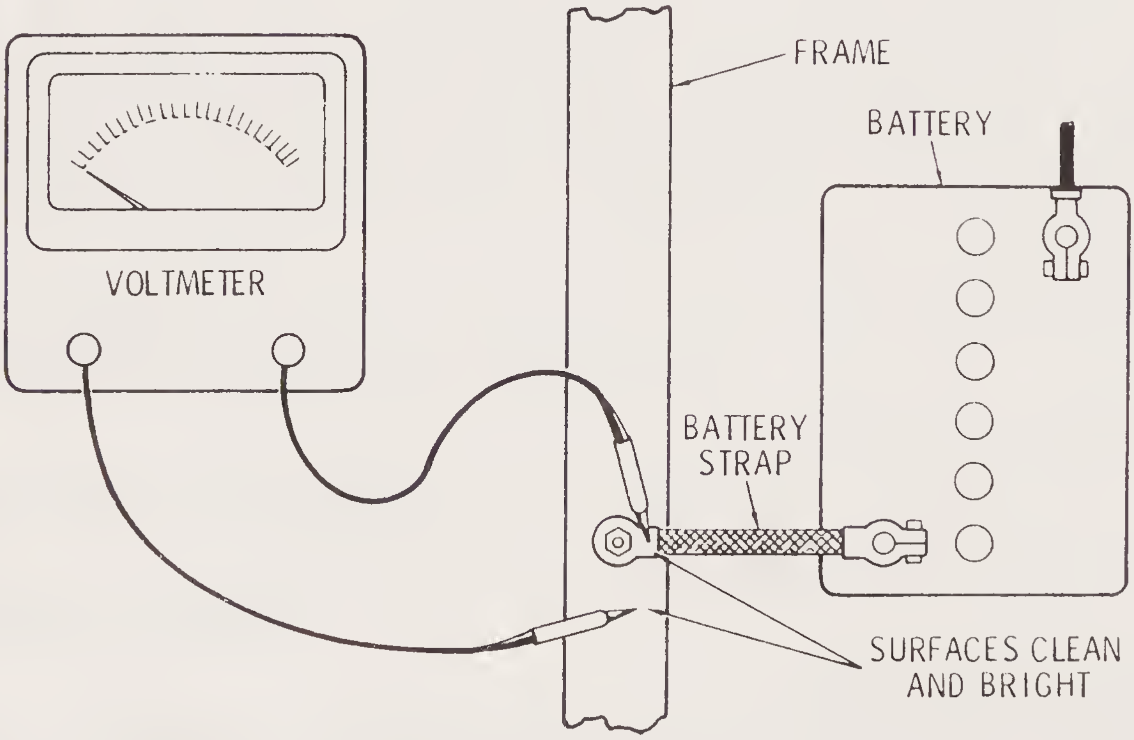



**Fig. 22-5. Testing efficiency of battery ground connections with a voltmeter.**

2. An ammeter with 0- to 50-ampere scale graduated in 1-ampere divisions.
3. A battery hydrometer.

The battery should be checked with a hydrometer to establish its specific gravity. If the battery is not fully charged, replace it temporarily with one that is. The ammeter should be connected with heavy short leads between the negative battery terminal and the negative battery cable. All checks should be made with the engine running and the generator or alternator charging at 10 amperes or more. Such a load may be applied by turning on the headlights and accessories. The voltmeter reading should remain stable.

If no readings can be obtained on the voltmeter, clean and tighten all ground connections, especially the frame bracket where it is bolted to the engine, and the battery ground strap.

## MAJOR ENGINE TUNE-UP

A major tune-up comprises an overall check and service as required. In addition to the tests and servicing included in a minor tune-up, a major tune-up includes such items as:

1. Battery.
2. Valve adjustment.
3. Bench distributor test.
4. Compression test.
5. Vacuum gauge test.
6. Complete ignition test.
7. Cooling system.

### Battery

Clean and tighten connections. Tighten all primary and high-tension wire connections, particularly at the ignition starter switch, ammeter and fuel gauge behind the instrument panel.

A specific gravity reading of the electrolyte must be taken

before adding water, as water will not mix with the electrolyte immediately and a true reading will not be obtained.

A battery in good condition should have a specific gravity reading of not less than 1.250. A battery with a specific gravity of less than 1.235 must be recharged. Add pure distilled water to bring level of electrolyte to ¼ in. above the plates in each cell.

## Valve Adjustment

Values for valve clearances are usually given with the engine hot, that is, at running temperature. Follow manufacturer's recommendations for the particular engine to be serviced. A typical method used to measure clearance is shown in Fig. 22-6. Here the clearance and thickness of feeler stock is greatly exaggerated so that they may be clearly visible. The adjustment is made with the valve tappet or lifter in the fully closed position to achieve a slight drag on the feeler gauge.

## Compression Test

Satisfactory engine operation depends on adequate and uniform compression in all cylinders. Loss of compression results in loss of power, and nonuniform compression in cylinders causes unsatisfac-

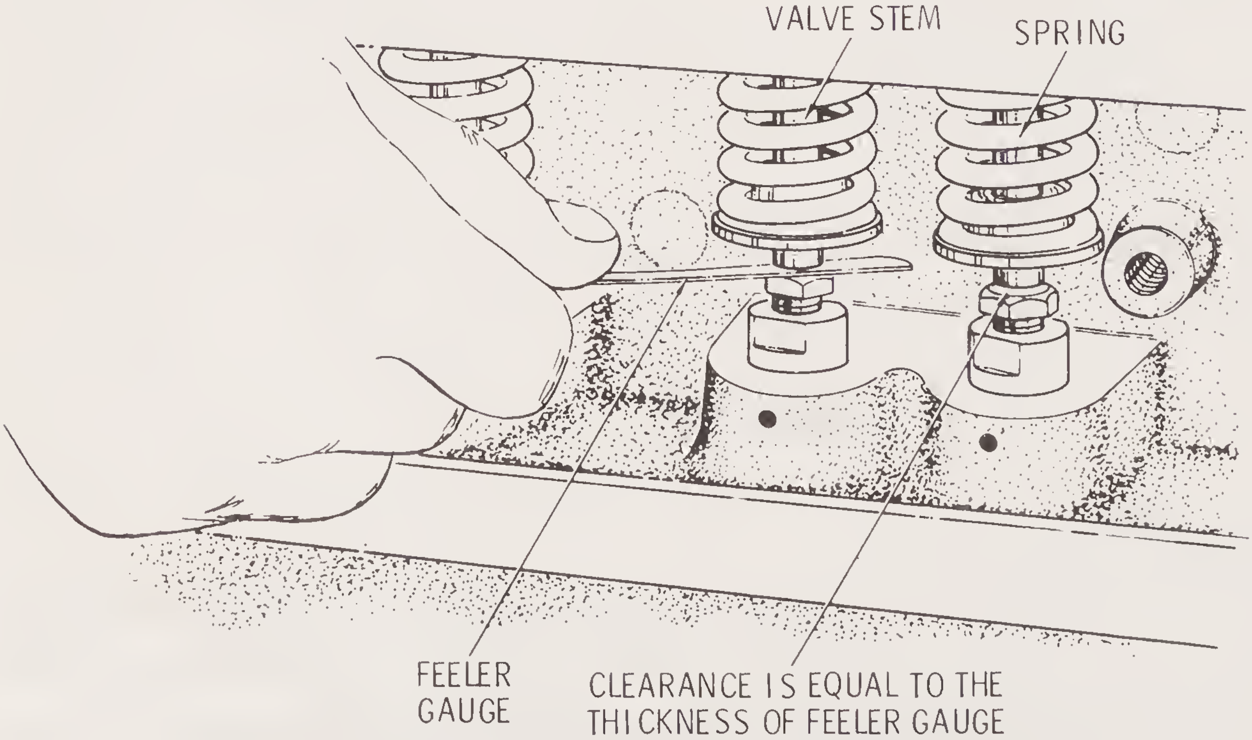



**Fig. 22-6. Adjustment of tappets by feeler gauge.**

tory or jerky operation. The compression test is therefore important.

When making the test it is essential that the engine be at operating temperature and that the engine oil be of the proper grade. To make the compression test, proceed as follows:

Remove spark plug of each cylinder to be tested and with engine warmed to working temperature, throttle open, ignition switch off and choke open. Apply compression test gauge to spark plug hole and crank engine. A check valve in the tester holds the compression in the gauge until released by the operator, permitting an accurate reading to be made. See Fig. 22-7.

Test each cylinder and record each reading. A variation in pressure is small in some makes of engines and large in others. The variation is principally due to lack of uniformity in combustion chambers.

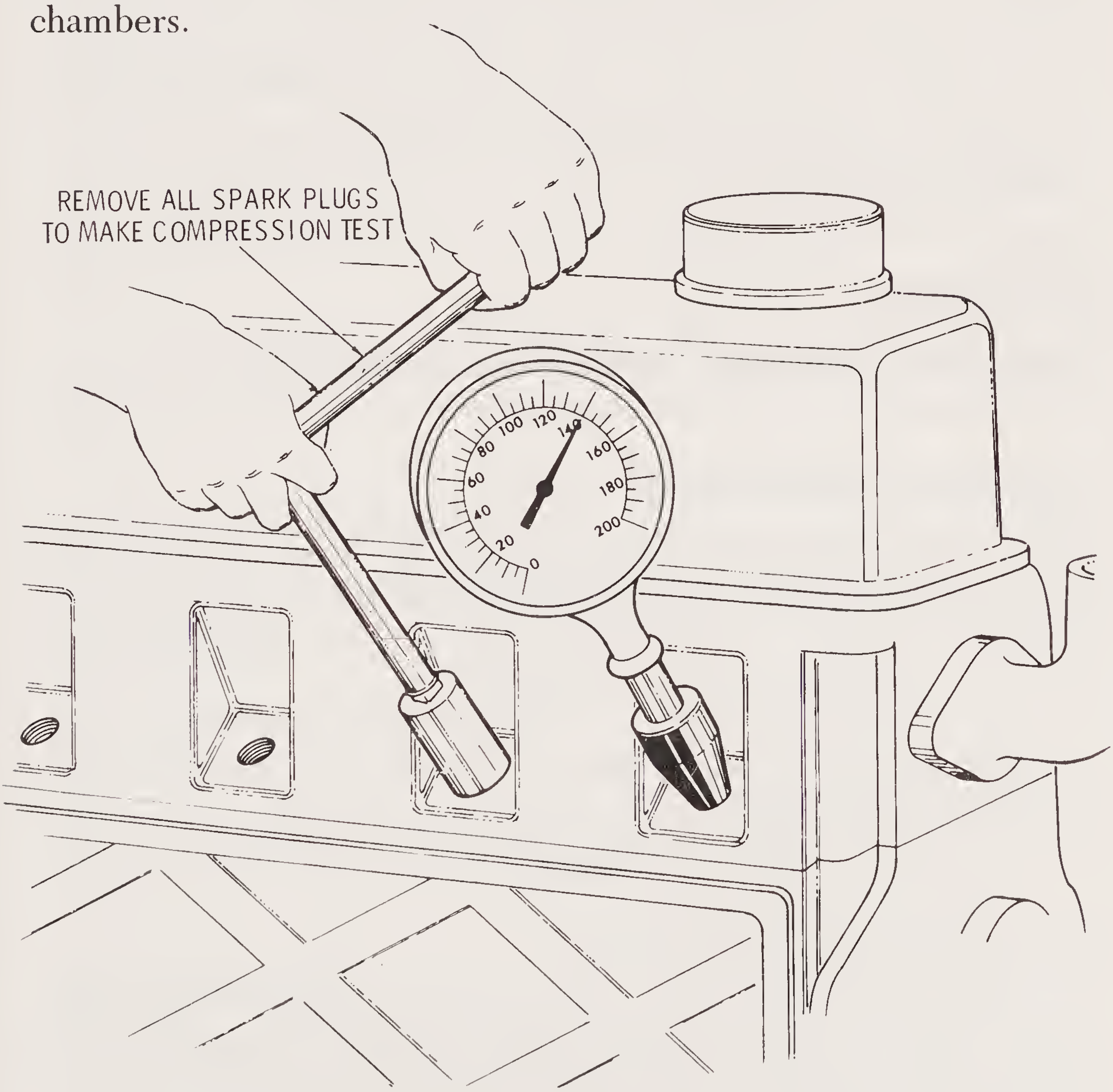



**Fig. 22-7. Typical compression gauge test.**

Summing up, it may be said that a pressure variation of 2 to 4 percent in a high-compression engine is permissible. If it is more, the cause for the low compression should be found and remedied.

## Distributor

In a testing machine, check distributor performance at various speeds. Check the mechanical advance and the vacuum advance. Test the condenser in suitable testing equipment, if available.

## Ignition Coil

Test with coil tester for output at high and low speeds, and for shorts or open circuits. Test coil at normal operating temperature, since a cold coil may appear to be satisfactory under test and yet may not be operating properly when warmed up to its normal working temperature.

## Fuel Pump

Check the fuel pump pressure with a low-reading pressure gauge.

## Carburetor Adjustment

When adjusting the carburetor, be sure the engine is at normal operating temperature. Use combustion analyzer for accurate adjustment. To ensure normal engine performance, the following adjustments should be made or checked:

1. Idle air mixture.
2. Idle speed control.
3. Accelerator pump (if adjustable).

### Idle-Air-Mixture Adjustment.

The idle needle valve controls the fuel mixture. When turned clockwise, it gives a leaner mixture, while turned counterclockwise it gives a richer mixture.

### Idle-Speed-Control Adjustment.

If a tachometer is available, connect to the engine, then adjust idle speed control screw either in or out until the speed specified by the manufacturer has been established.

### Accelerator Pump.

In order to provide the additional fuel required for rapid acceleration, the carburetor is equipped with a pump which supplies an extra charge of fuel momentarily as the throttle is opened.

There are settings provided on the accelerator pump to give a greater or lesser discharge of fuel depending upon spring or lever position. Adjust accelerator pump to manufacturer's specifications.

## Cooling System

In order to get the maximum efficiency from the cooling system, it must be kept clean. There is a tendency toward corrosion of parts due to electrolytic action of water containing minerals and aging antifreeze.

Both the corrosive scale and the mineral deposits tend to coat the cooling surfaces, reducing radiation, and in time will clog the radiator surfaces unless special steps are taken to prevent these deposits.

The cooling system should be cleaned at least every two years. This cleaning is most effective when reverse flushing is used to remove deposits after they have been loosened by the use of a good cleaning solution.

### Cooling System Protectors.

The regular use of a quality permanent antifreeze and inhibiting fluid in the cooling system and periodic reverse flushing will greatly reduce the formation of rust, scale and corrosion.

## Fan Drive Clutch

When the engine is cold and not operating, the fan should be easily rotated by hand (be sure fan belt is tight). Start engine and allow it to warm up to normal operating temperature. After it has warmed

up, allow engine to run for *at least* 5 minutes. Turn off engine and *immediately* check to see if fan can be rotated (use gloves or a cloth to protect your hands). If it takes a great amount of effort to rotate the fan, the *fan drive clutch* is operating properly. If little effort is required, the clutch should be replaced.

CHAPTER 23

# Piston and Piston Ring Service

When cylinders and pistons are properly machined and there is proper clearance and lubrication, there is no reason for excessive wear. When any one of the foregoing requirements are not obtained, abnormal wear will result.

There may be ample lubrication, but if the oil is dirty or mixed with water, its efficiency is greatly reduced. Under good lubrication conditions with clean oil of the proper viscosity, appreciable wear will take place only after a very extended period of service.

## EXPANSION OF PISTONS

Each piston type has its own expansion characteristic under variable temperatures in operation. This governs the method of finishing to

be used for best results. Operating temperatures to which a piston is subjected depend upon several conditions:

1. Working loads.
2. Fuel and lubricant.
3. Climatic conditions.
4. Cooling.

The expansion of a piston depends on the rise in temperature; hence this must be taken into account in determining the clearance to be given in fitting.

The temperature range will depend on the service conditions. Thus engines of light-duty cars will not be subjected to so great a temperature range as heavy-duty engines, and it follows that more clearance must be given pistons for heavy duty than for light duty.

## REMOVING PISTONS FROM CYLINDERS

In some engines, pistons may be removed from the bottom; on most they must be removed from the top. If the cylinder is worn, the ridge at the top or bottom may need to be removed first. This is accomplished with a special tool (cylinder ridge reamer) made especially for the purpose.

For removal, take off cylinder head and oil pan and turn crankshaft until the connecting rod is on bottom dead center. Remove connecting rod cap and push up rod clear of crank pin; place cap in position and bolt together loosely so that it will not get mixed with the other caps. With any soft tool such as a screwdriver or hammer handle placed inside the piston, push up piston until the first ring is above the cylinder and has sprung out so it will hold piston suspended. By grasping the end of the piston, the assembly of piston and rod may be lifted out of cylinder.

On engines where the piston may be removed from the bottom of the block, rotate the crankshaft until the counterweights are crosswise of the cylinder block and opposite the camshaft. Using a soft tool, drive the pistons from the top slowly out the bottom. Never allow the piston to drop or allow the rod bolts to touch the bearing surface of the crankshaft. Pieces of plastic or rubber tubing placed over the rod bolts will protect against this.

## FITTING PISTONS

First, check piston and pins removed from engine with new pistons and pins before installing, to avoid possible errors in ordering (Figs. 23-1 and 23-2). Make certain that cylinders are round, the same diameter top and bottom, and at right angles to (square with) the base.

The piston should be fitted to the cylinder with the manufacturer's clearance, and not more. Failure to provide proper clearances may cause either scored cylinders or seizure. Particular care must be used to give the rings sufficient end and side clearance; failure to do this might also cause seizing.

In the installation of a piston, never use force on any part of it or in any way. Should it be necessary to place pistons in a lathe or grinder, it is difficult to secure the greatest accuracy with any device that exerts either inside expansion or outside pressure.

While bell centers or chucks may be used, for best results a universal grinding and turning arbor, or any similar device that will positively maintain uniform roundness while the pressure of tool or grinding wheel is being applied, should be used. This permits an experienced workman to remove accurately even as little as 1/1000 in. of material from the outer surface.

When reassembling the engine, cleanliness is most important.

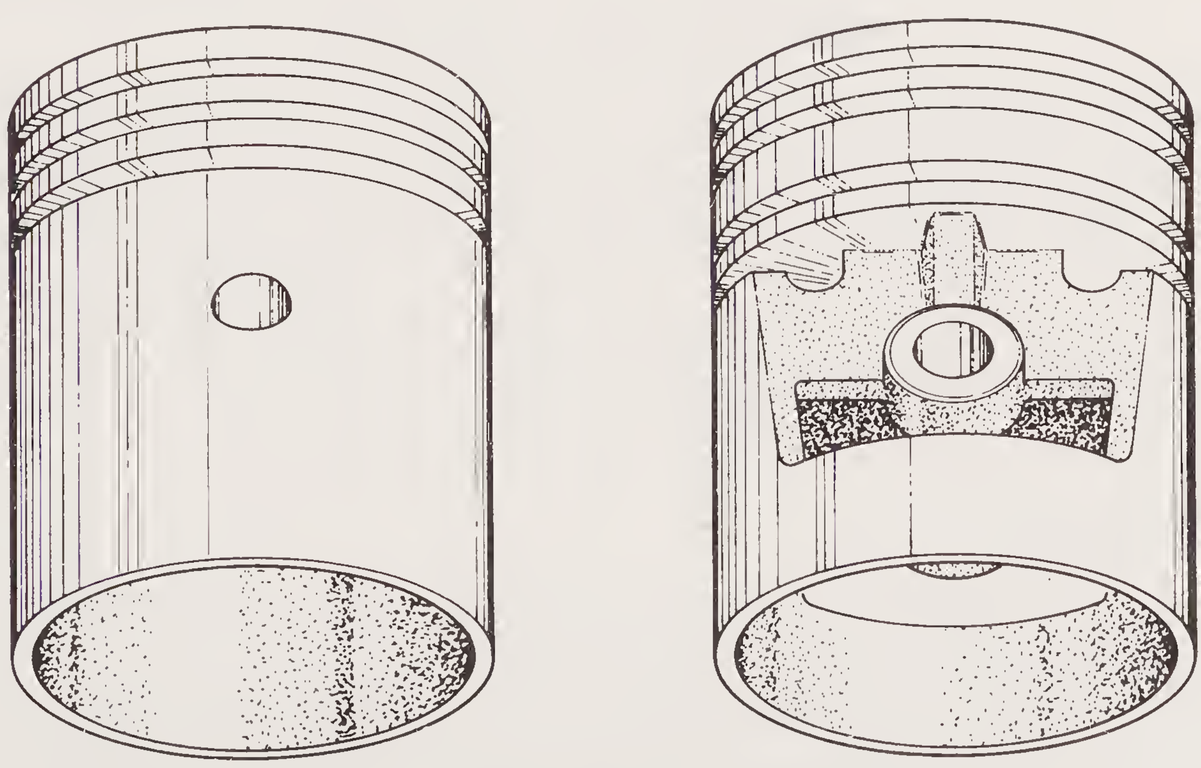


**Fig. 23-1. Cam-ground piston and piston with supporting band.**

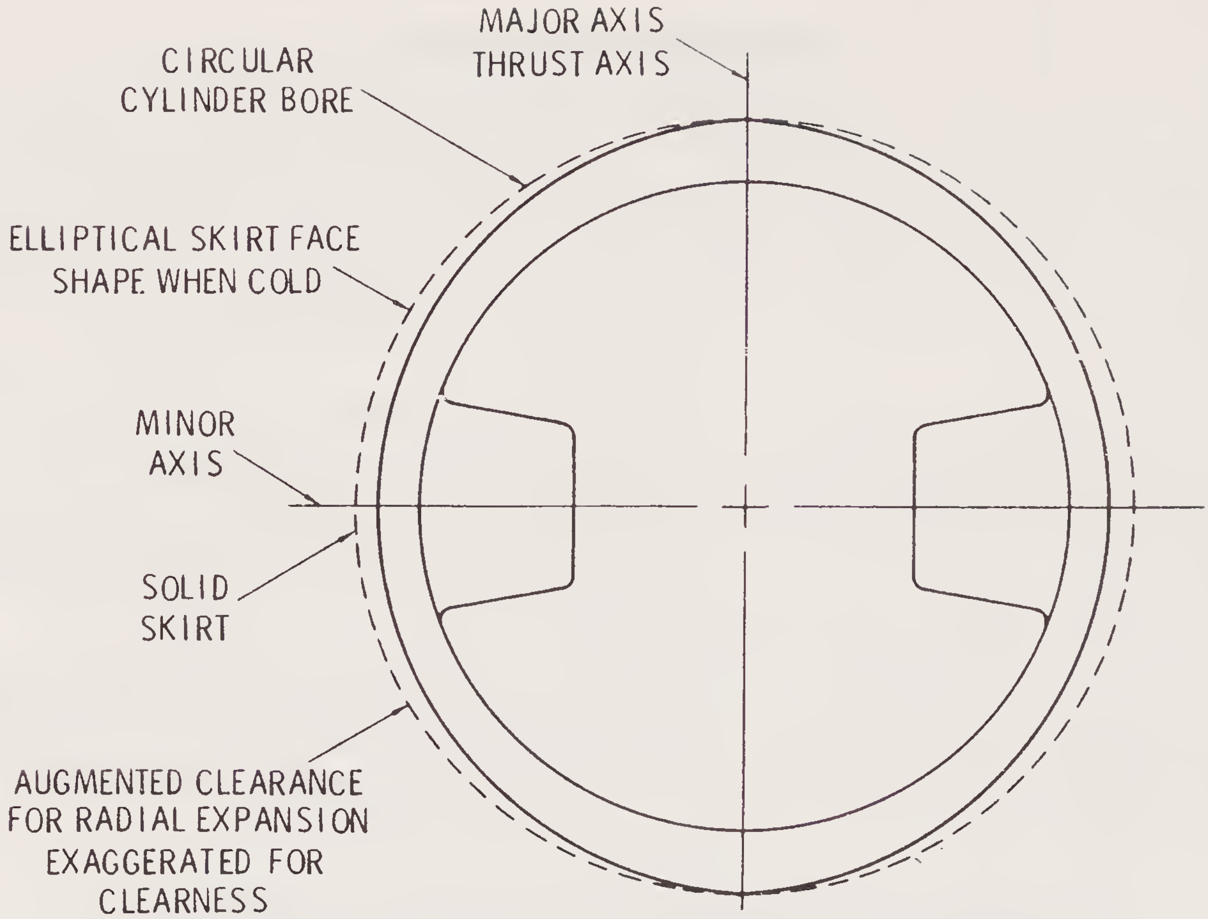



**Fig. 23-2. Bottom view of piston illustrating cam grinding.**

Dirt and chips must be eliminated or all the care used in fitting various parts may be nullified. Just before installing, dip piston in oil and be sure that the entire engine is properly lubricated.

## PISTON RING SERVICE

In ring installations, the selection of the proper type piston rings is of great importance in ensuring a satisfactory job. Great advances have been made in the manufacture of rings and there are many types from which to select. The adaptation of the leading types as briefly given here will be found helpful to the serviceman in selecting the proper rings for best results.

### Top Ring

Most manufacturers of engines today use either chrome-plated or moly-filled top compression rings. In almost all cases, except those in which only a temporary repair of damaged or worn cylinders is to be accomplished, rings of the same type should be used. Chrome-plated rings are typically used in conditions where abrasive materials

in the air are a problem. Moly-filled rings have become the most popular due to their ability to seat faster and hold lubrication, enabling them to last longer with less cylinder wear.

### Center Ring

Cast-iron or steel rings remain the standard for the second ring (and third, if used). These softer rings seat quickly and produce less cylinder wear than do chrome-plated or moly-filled rings. They are also durable in the lower grooves, where the force of compression holding them against the cylinder walls is much less than that applied to the top ring.

### Oil Ring

Most manufacturers have progressed to using three-piece oil control rings. These rings utilize a combination of two thin outer rails, usually chrome-plated stainless steel, and a combination spacer-expander. This arrangement provides a ring with greater ability to conform to the cylinders and more oil storage and return area than the older one-piece iron or steel rings.

### Fitting Rings

In fitting rings, great care should be used to determine that they have proper end clearance. Care should also be exercised in following the ring manufacturer's specifications as to the proper ring setup for various types of pistons. After removing pistons, carefully examine the cylinders.

Wash the rings thoroughly with solvent and dry with compressed air. Measure the cylinders to determine the amount of wear, taper or out of roundness (Fig. 23-3). In badly out-of-round, tapered or scored cylinders, they should be rehoned or rebored and new pistons fitted.

Next, examine the pistons (if new pistons are not being installed), using micrometers to determine if they are worn or warped (Fig. 23-4). Clean the ring grooves thoroughly, removing all carbon.

Fit the rings to the cylinders first, starting from the top of the bore and forcing them downward to be sure that they have enough

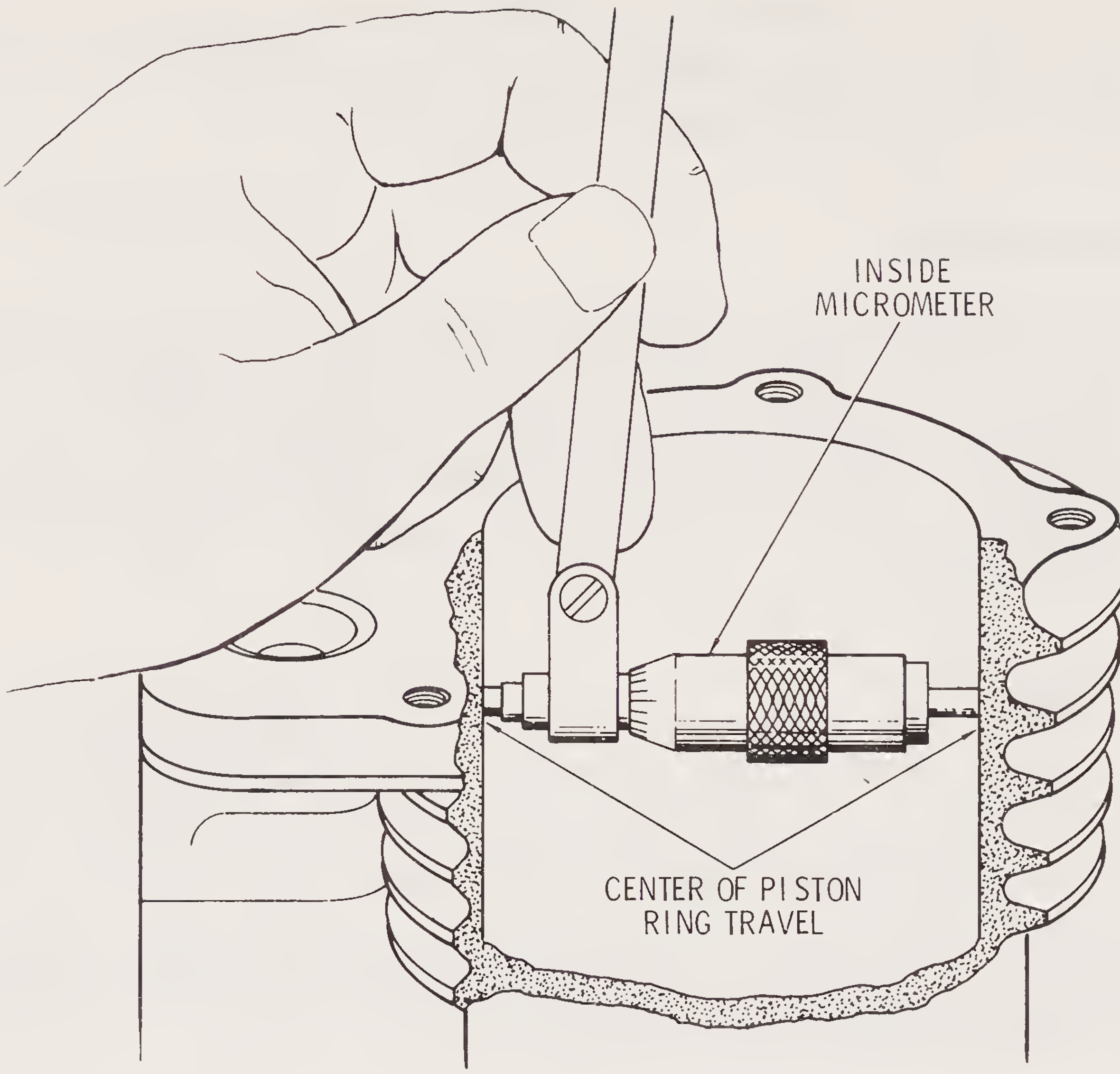



**Fig. 23-3. Checking cylinder bore with inside micrometer.**

clearance at the end gap all the way through the cylinders. See Fig. 23-5.

If the cylinders are not to be rebored, measure top and bottom of the cylinder, because the cylinders always wear tapered and are larger at the top than they are farther down.

Do not fit piston rings too tightly. Cylinders should be carefully measured and rings fitted with proper clearance at the smallest point of the bore, if cylinders are tapered.

Check cylinders for ridges at the top and bottom of ring travel caused by cylinder wear. After new bearings are installed, the bottom or top ring may strike such a ridge, damaging the rings.

Next, try the ring in grooves of the piston, rolling it around in the grooves. Rings should be loose enough in the piston grooves to fall to the bottom of the grooves when the piston is held horizontally.

Worn piston grooves greatly reduce ring efficiency; for good

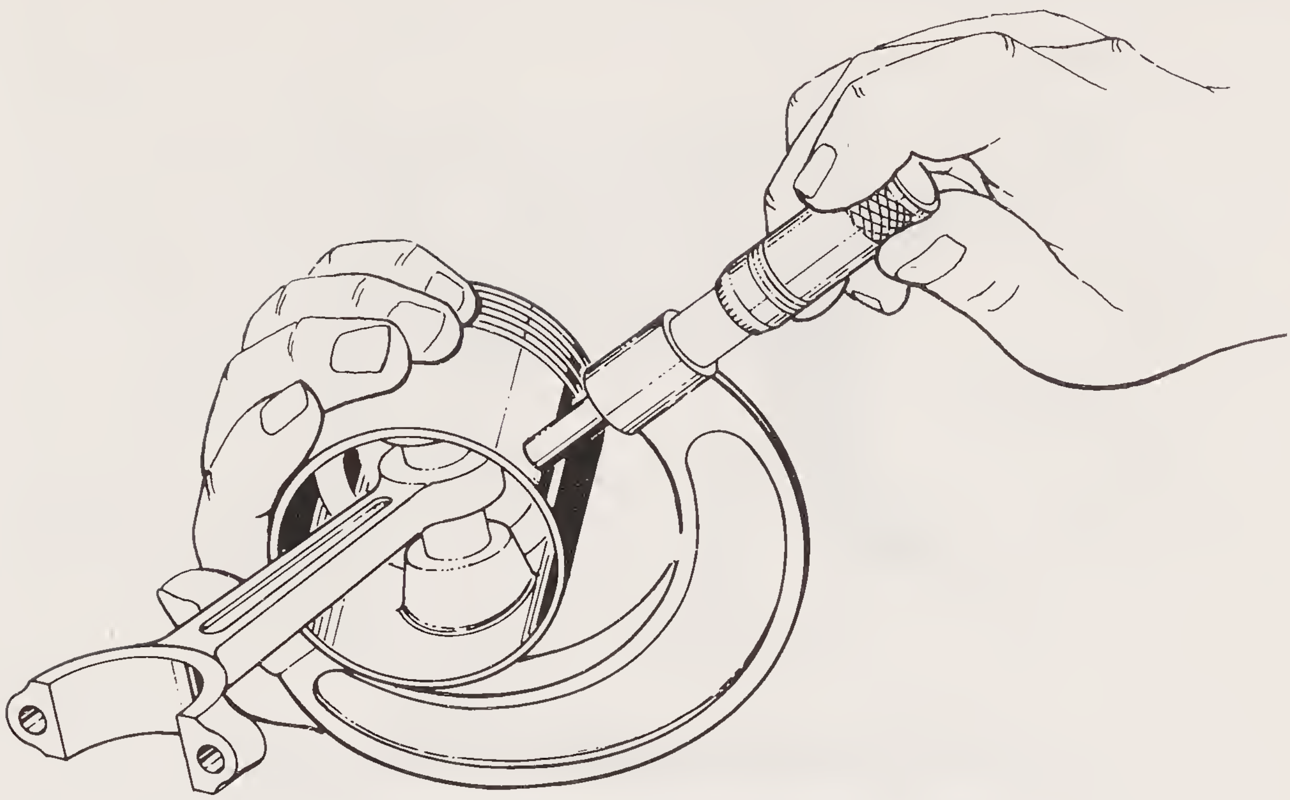


Fig. 23-4. Checking piston with micrometer.

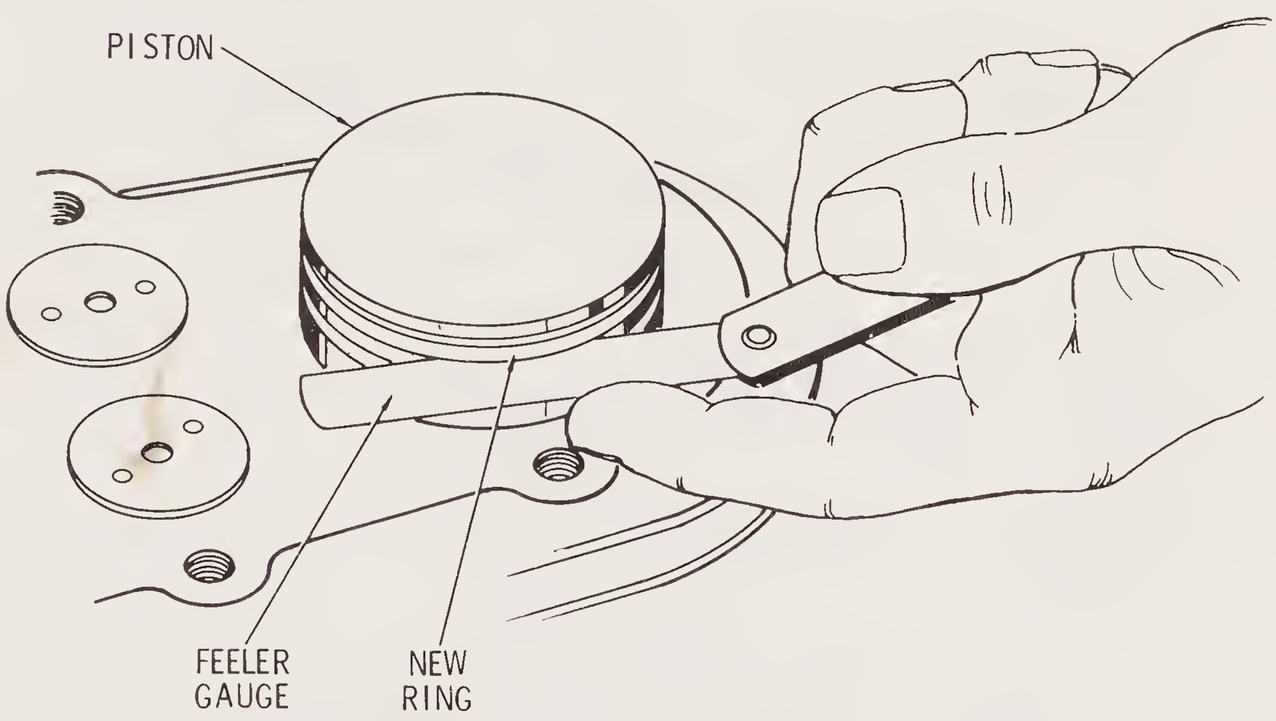



Fig. 23-5. Checking ring gap with feeler gauge.

engine performance, the rings must fit the grooves of the piston properly. Piston with worn grooves should be replaced.

When a test proves that the rings fit the grooves (Fig. 23-6), equip the piston by installing the lowest ring first (Fig. 23-7). After the rings have been installed in the grooves, turn them around several times to be certain that they will rotate freely and not stick.

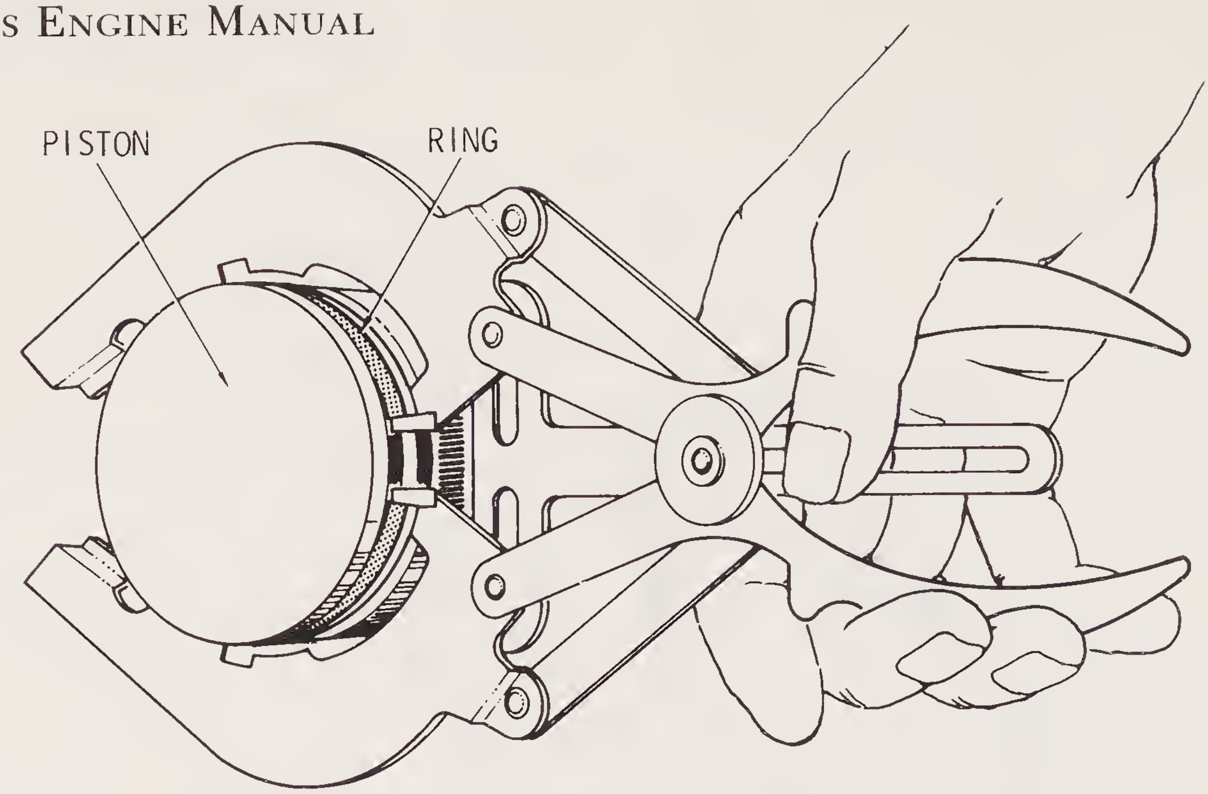



Fig. 23-6. Checking ring groove with feeler gauge.

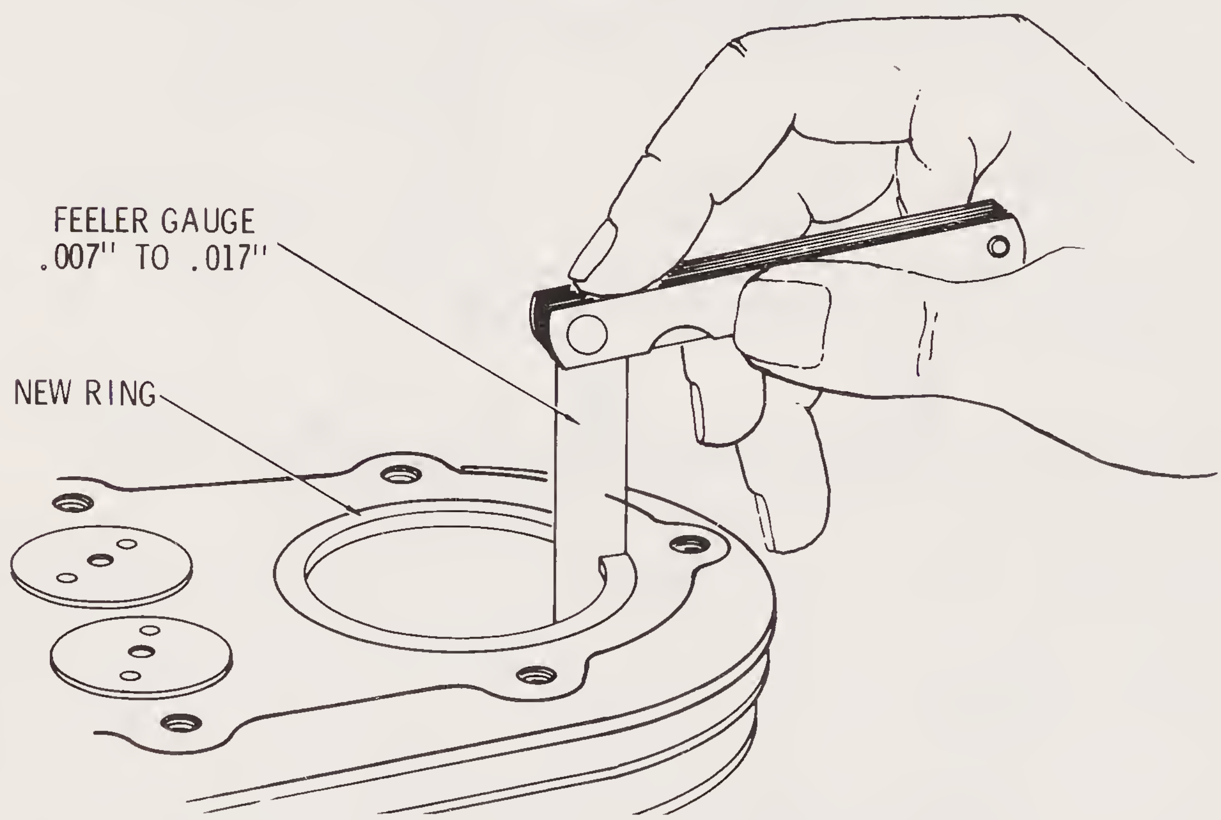



Fig. 23-7. Tool used for removal of piston rings.

Before returning the fully equipped pistons to the cylinders, be sure they are free from all grit and dirt and well oiled. Old piston rings should never be refitted to the piston, as it takes much longer for old rings to seat in again than it would for new rings. This is because old rings can never be mounted in the same position as they were while in the engine. It is better always to install new rings. Use care in ordering correct size and type rings for each job.

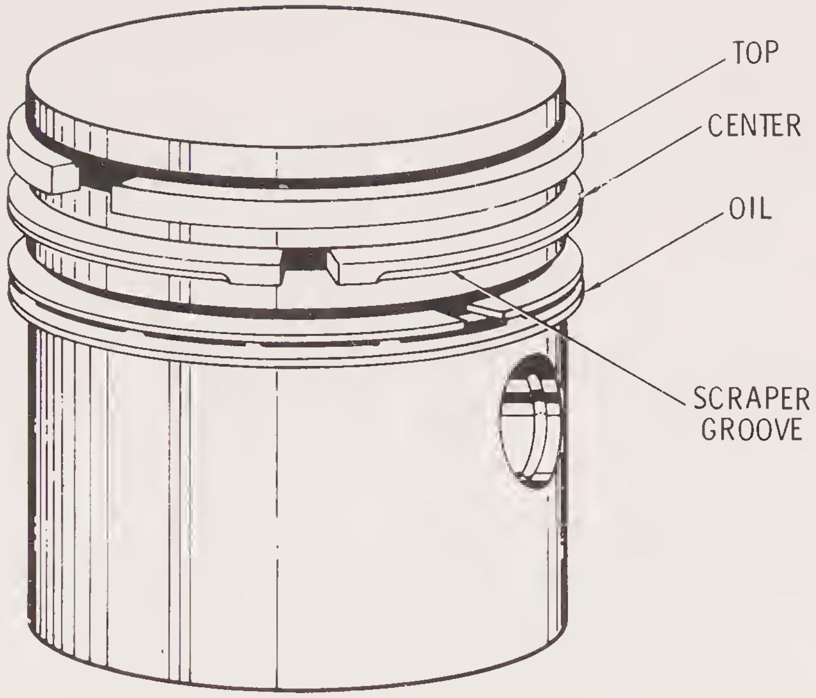



**Fig. 23-8. Position of piston rings.**

Whenever the new piston rings are installed, drain the crankcase and fill with the best grade of oil.

In fitting piston rings, note the following "don'ts":

1. Don't fit new rings into worn piston grooves.
2. Don't file piston rings excessively.
3. Don't fit piston rings too tight.
4. Don't guess at the size required; measure the cylinders.
5. Don't fit an oversize ring into a tapered cylinder unless it has sufficient clearance at the smallest diameter.

Oil pumping and compression leakage can be traced to the following causes:

Worn, out-of-round cylinders.

Scored cylinders or pistons.

Worn ring grooves.

Poor piston rings.

Poorly fitted pistons and rings.

Poorly aligned rod and piston assembly.

Worn bearings.

CHAPTER 24

# Cylinder Block Service

In operation, the cylinder of a gas engine wears out of true because of the angularity, or various angular positions, the connecting rods pass through during the compression and power strokes. The cause of wear is the lateral thrusts of the piston against the cylinder walls, due to compression and power impulses.

The compression thrust acts on one side of the cylinder and the power or impulse thrust on the other as indicated in Fig. 24-1. The result is to change the cross-sectional shape of the cylinder from circular to elliptical. This results first in a loss of compression, which, together with the greater leakage during the power stroke is one of the causes of power loss in old engines.

Fig. 24-1 is drawn under the assumption that the thrust is constant during the entire stroke in order to show more clearly that the compression thrust wear on the right side is less than the power thrust wear on the left side. In actual operation, however, the thrust

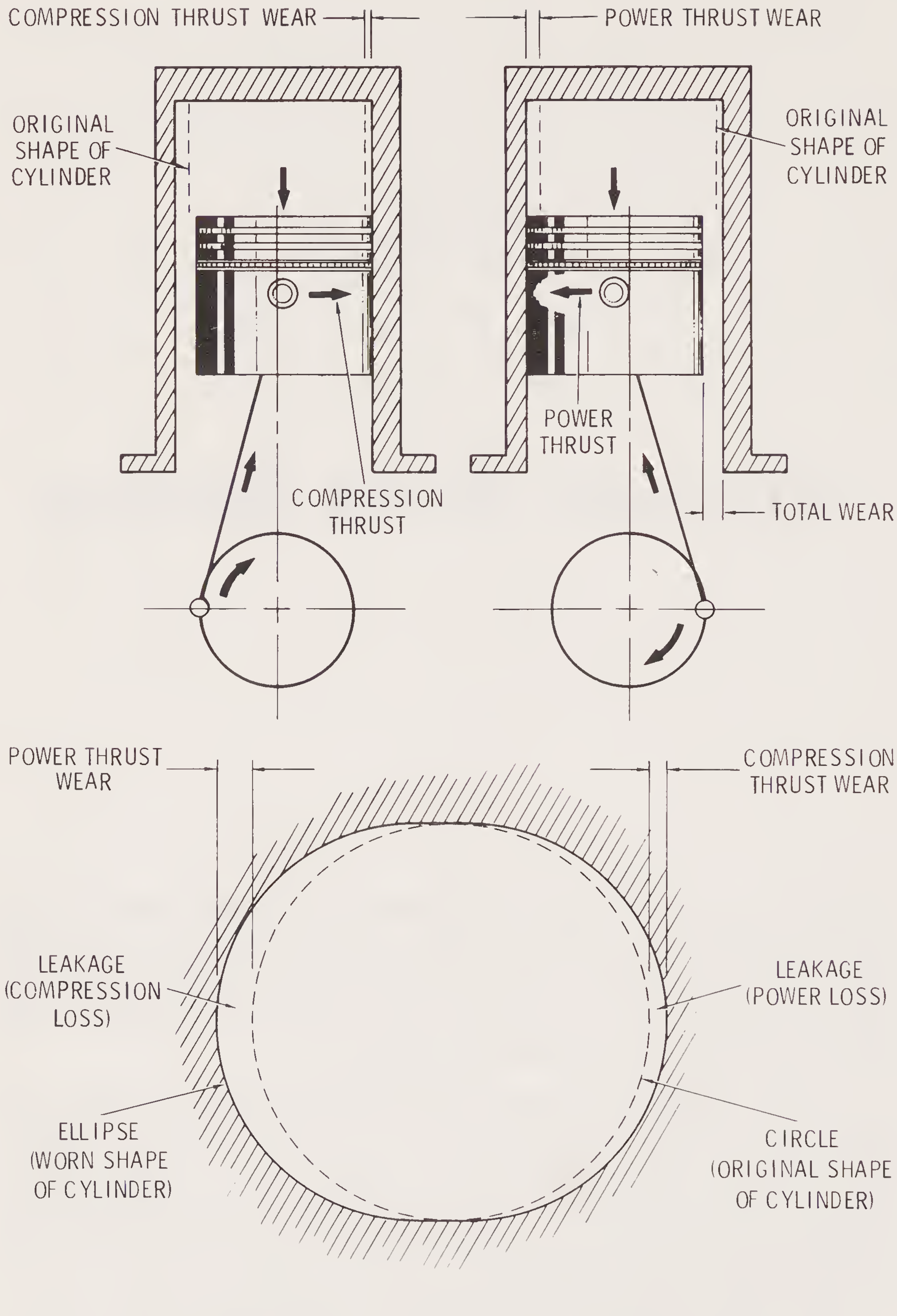



**Fig. 24-1. View of compression and power thrusts of piston and wear they cause.**

is anything but constant, varying at all points of the compression and power strokes.

When the scoring is too deep to be removed by honing, it will usually be necessary to remachine the cylinder bore slightly oversize, and refit the cylinders with oversize pistons and rings. In some cases of cylinder scoring it may be possible to bore the cylinder to a considerable oversize and press a prepared sleeve of the exact size required into the cylinder.

## RECONDITIONING CYLINDER BORES

There are various methods of reconditioning cylinders:

1. Honing
2. Boring
3. Sleeving

### Honing

This operation is performed by a tool which consists of a cylindrical frame on which are mounted grinding stones that are pressed against the cylinder walls by springs or expanders.

There are two basic types of cylinder hones. The first type is known as a flexible hone and is often termed *glaze breaker*. It has no means of controlling exact cutting pressure or limiting the amount of its cut. It usually contains three or four relatively fine abrasive stones and a spring that is used to force the stones against the cylinder wall. This type of hone removes material very slowly and should be used only to deglaze cylinders in good condition and showing little wear or scoring.

Ridged hones are the second classification. A ridged hone utilizes two stones and two shoes or sliders. The shoes hold the hone centered very precisely. A calibrated control is used to set the exact cutting pressure and limit the size of the finished cylinder. Ridged hones can remove minor wear and considerable scoring. Because they can remove material relatively quickly yet precisely, they are often used to finish sizing cylinders after boring or sleeving.

## Boring

Boring a cylinder is the preferred method of correcting for normal wear or scoring. It consists of preforming with a special precision cutting device known as a *boring bar*. The bar may bolt directly to the engine block or may be held, along with the block, in a special fixture. The bar is usually adjusted to cut only a portion of the total material to be removed at one time, therefore requiring multiple passes of the cutting tool. Usually, the last cut is adjusted to a size one- to five-thousands smaller than the factory-specified finished cylinder size to allow for precision honing. The finished size depends on the dimensions of the oversize pistons to be installed. Standard oversizes include 0.010, 0.020, 0.030, 0.040, 0.060, 0.080, 0.100, 0.125 in. Standard practice dictates that a size be chosen that will clear the worst damaged or worn cylinder, with all cylinders being bored to that size.

## Sleeving

Sleeving is used only in cases of extreme cylinder wear or damage, or in the case of damage to only one cylinder where boring and replacement of the other cylinders/pistons is not required. Sleeving also requires the use of a boring bar. The cylinder is bored to a very large oversize so a sleeve may be pressed into the block. The sleeve is usually bored and honed after installation to ensure a true cylinder.

# OTHER BLOCK SERVICE

Two remaining operations that may be necessary to perform when preparing the cylinder block for overhaul are resurfacing and line boring.

## Resurfacing

Resurfacing becomes necessary when the head gasket surface of the block becomes warped or distorted due to overheating or head bolt retorquing. The block is held in a special fixture that uses the lower

gasket surfaces and/or main bearing journals for alignment. The head gasket surfaces are then either ground with an abrasive wheel or cut with a mill until the surface is restored.

### Line Boring

Line boring becomes necessary when the main bearing journals or camshaft bearing bores become out of alignment, usually from overheating or block fatigue. When line boring the main journals, the bearing caps to the block mating surface are machined first to decrease the size of the bearing opening, then remachined to the proper size. When line boring the camshaft journals, oversize outside-diameter cam bearings must be used.

## REMOVING CARBON

When cylinder walls and valve chambers have become coated with carbon during operation, the carbon must be removed to avoid preignition and the resulting unsatisfactory operation.

*To remove carbon*, it is scraped off with a hard, sharp-edged tool. For cleaning out the ring grooves, a special tool should be used made to fit so closely as to leave no deposit under the end or by the edges. Keeping the deposits moist with kerosene will facilitate their removal; soaking with kerosene for hours or even days will be even better. For surfaces that can be reached in this manner and that will not be injured by the wear it will cause, finishing may be done with coarse emery cloth, held in the hand or around a stick. Carbon can also be removed by burning, but this method is not recommended unless properly done by an expert. Otherwise damage may result.

The best method of removing carbon is with glass-bead blasting. Cylindrical, fine, nonabrasive glass beads are propelled by high-pressure air using sand-blasting equipment at carbon-coated piston surfaces. This method will completely remove all traces of carbon or corrosion, but requires complete disassembly of all parts and very thorough cleaning afterwards to remove all traces of dust and glass beads.

### Importance of Cleaning

The serious trouble experienced by not thoroughly cleaning a reconditioned job cannot be overemphasized. Recondition tool manufacturers have united in their efforts to overcome this practice of carelessly finishing and cleaning reconditioned jobs. A cylinder that is rough or has not been throughly cleaned acts as a lap and causes excessive wear to the entire piston assembly and results in dissatisfaction to all parties concerned.

*During the first half of the stroke* (approximately), where the mean effective pressure is high and the angularity of the connecting rod is increasing, the wear is greatest and is called the *zone of maximum wear.*

*During the second half of the stroke*, where the mean effective pressure is low and the angularity of the connecting rod is decreasing, the wear is less and is called the *zone of minimum wear.* This action tends to wear the walls partly cone-shaped or tapered, made more pronounced because the lower cylinder walls receive better lubrication than the upper walls. From the foregoing it follows that when cylinders are worn both out of round and tapered, refinishing to a true surface becomes necessary.

## SCORING OF CYLINDERS

Seizing and sticking of pistons in the cylinders is commonly due to overheating or lack of lubrication or both. In almost every case of this sort, piston rings will be damaged and cylinders scored. Such scratches or scores will run lengthwise in the cylinder walls and, if not too deep, may be honed out with a suitable cylinder hone prior to substitution of new piston rings.

CHAPTER 25

# Connecting Rods and Crankshaft Service

It is important to locate engine knocks in order to avoid disassembling any more of the engine than necessary. Engine knocks due to a loose or malfunctioning connecting rod may be located by the aid of a sound rod or, preferably, a stethoscope.

Some mechanics locate a knock by cutting out or shorting one cylinder. This is done by short-circuiting one spark plug. This brings less load on the piston and connecting rod of the short-circuited cylinder, thus reducing the noise. The shorting out of one spark plug at a time will assist in locating the cylinder or rod which is at fault in cases where the noise is not due to looseness in all cylinders or rods.

## FITTING CONNECTING ROD BEARINGS

A connecting rod bearing consists of two halves, or shells, which are alike and usually interchangeable in the rod and cap. When the

shells are placed in the rod and cap, the ends extend slightly beyond the parting surfaces so that when the rod bolts are tightened, the shells will be clamped tightly in place to ensure positive seating and to prevent turning. A small tang is formed on the back of both bearing halves that lock into notches in the rod to prevent the bearing from spinning further. The ends of shells must never be filed flush with the parting surface of the rod or cap. See Fig. 25-1.

Since these bearings are renewable, there will be no need for shims to be inserted to facilitate proper fitting. Renewable bearings at the crank end serve to reduce time and expense should the bearing material wear sufficiently to require replacement.

It also eliminates the necessity of changing connecting rod

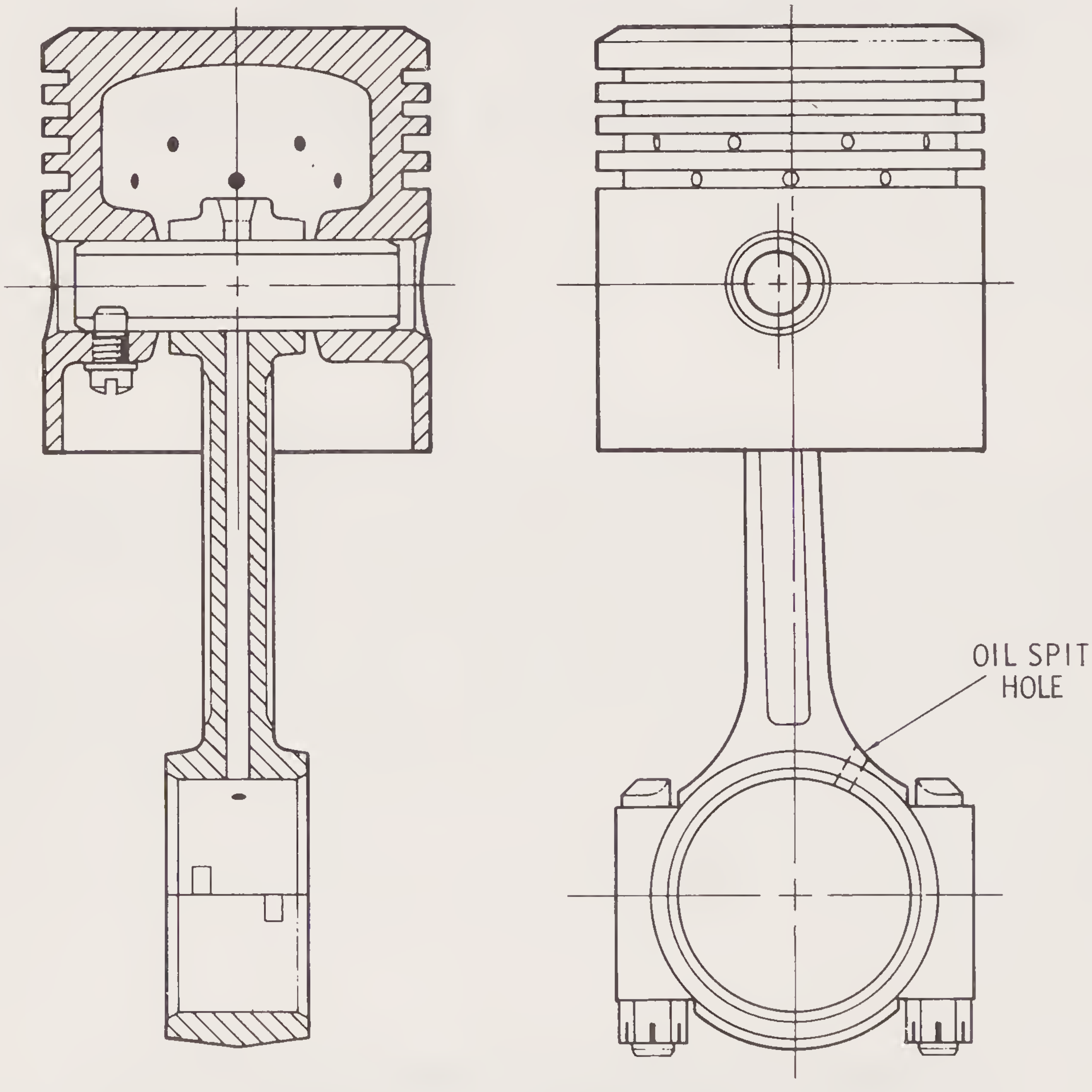



**Fig. 25-1. Typical rod and piston assembly. When installing connecting rods, oil spit hole in connecting rod bearing usually is toward the no-valve side of the engine.**

assemblies, the only operation necessary being the removal of the old bearing and installation of new ones, which may be done without removing the rods from the engine. There are, however, some notable exceptions.

## CRANKSHAFT SERVICE

The modern crankshaft is a highly developed piece of mechanism made of the best material and machined with precision. As an example of construction, many automotive engine crankshafts are made from a drop forging of high carbon alloy steel carefully heat treated.

As previously noted, the crankshaft is one of the most important parts of an engine, as it ties together the reaction of the pistons, transforms the reciprocating motion of the pistons and connecting rods into rotary motion, and transmits the resulting torque to the flywheel and load. As a result, the crankshaft is subject to heavy vibration and stress and may develop tiny cracks, particularly at or near the ends of the connecting rod throws or at the ends of the main bearing journals. See Fig. 25-2 for crankshaft and related parts.

### Reconditioning of Crankshafts

When the crankshaft is free from flaws or defects and the journals are worn slightly tapered or out of round, the shaft may be reground and fitted with undersize bearings. To recondition the crankshaft and install undersized bearings, reduce the journal diameter by the amount which the bearings are undersized.

For example, if .010 in. (0.254 mm) undersized main bearings are to be installed, the original journal diameter of 2.4370 in. to 2.4375 in. (61.899 mm to 61.912 mm) should be reduced to 2.4270 in. to 2.4275 in. (61.645 mm to 61.658 mm).

## CHECKING BEARING CLEARANCE

Limits on the taper or out-of-round of any crankshaft journal should be held to .001 in. Undersize bearings should be installed if the crankshaft journals are worn enough to increase the bearing clearance above specifications. Never install an undersize bearing that

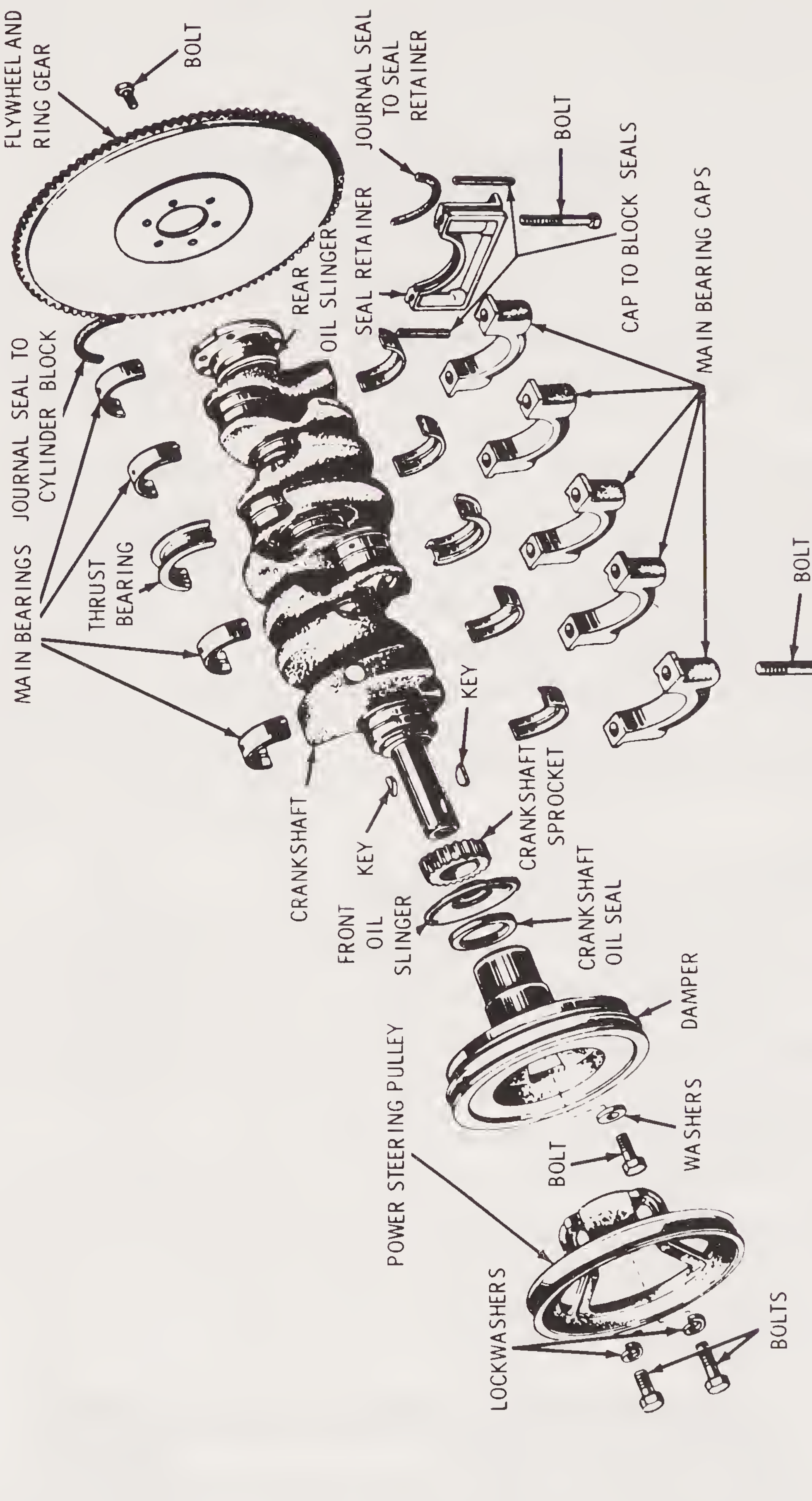



**Fig. 25-2. Typical automotive-type crankshaft and related parts.**

will reduce the clearance below specifications. The desired connecting rod clearance is specified by the manufacturer in an authorized factory service manual.

## CLEARANCE MEASUREMENT

The accepted method of clearance measurement is to measure the diameter of the journal with a micrometer caliper. The diameter of the shaft is measured at several points around the circumference to determine the size and check for roundness.

An alternate method is to use the *plastigage*, which consists of a waxlike material that will compress evenly between the bearing surfaces and journals without in any way causing damage to them (Fig. 25-3). To obtain accurate results, certain precautions should always be observed.

When measuring the main bearing clearance by the plastigage method, the surface of the crankshaft journal and bearing shell should be wiped clean of oil before the plastic material is placed in the cap. Place a piece of plastigage, approximately as long as the bearing shell across the bearing surface. Install and tighten the cap to recommended torque. The crankshaft should not be turned while making this check. After the correct torque is obtained, the bearing cap is removed. The flattened plastigage will now be found adhering to either the bearing shell or the crankshaft.

One edge of the envelope in which the plastigage is packed is marked in a graduated scale correlated to measure the width of the

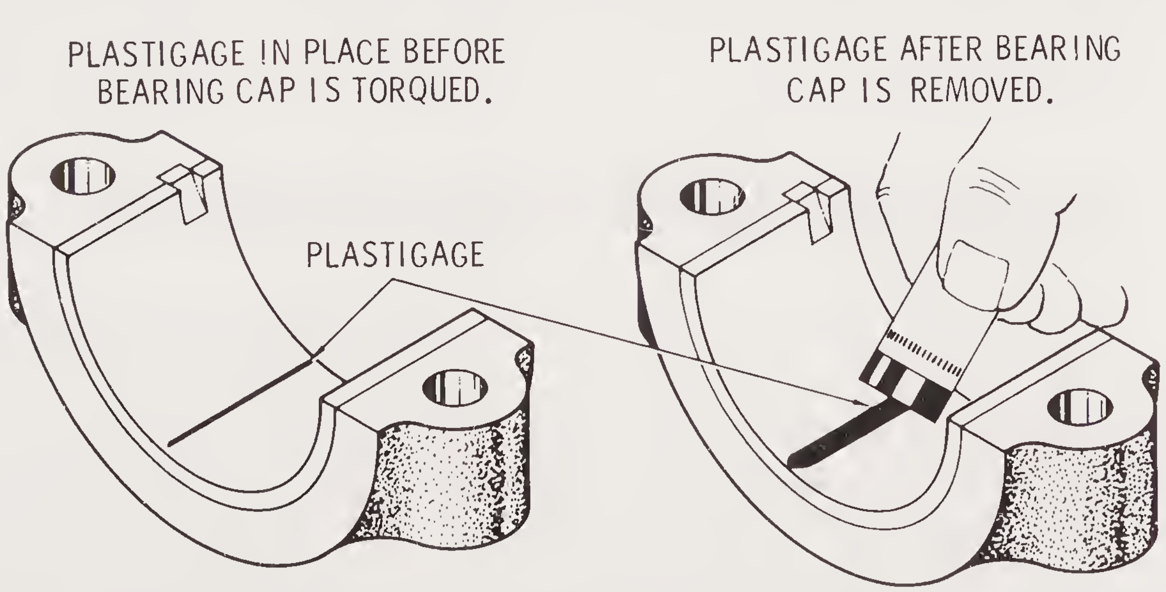



**Fig. 25-3. Checking bearing clearances with plastigage.**

compressed wax thread in thousandths of an inch. Compare the width of the flattened plastigage at its widest point with the graduations on the envelope. The clearance in thousandths of an inch will be indicated by the number of graduations that most nearly fit the width of the flattened plastigage.

If the bearing clearance is excessive, crankshaft journals should be checked for out-of-round and taper. Then, if necessary, the crankshaft should be removed and the journals reground. Replacement bearings are available in standard and the following undersizes: 0.001, 0.002, 0.010 and 0.012 in. Tighten rod cap nuts to the required torque.

CHAPTER 26

# Valves and Valve Gear Service

The prevailing cause of compression losses, particularly in older engines, is valve leakage, and therefore it is of the utmost importance that the valves be maintained in good condition so that they will seat properly.

## RECONDITIONING VALVES AND SEATS

### Preliminary Operation

First the cylinder head and valve or tappet covers must be removed to gain access to the valves. After the cylinder head has been removed from the engine and all of the parts disassembled from it, all carbon should be thoroughly cleaned from the combustion chamber, valve ports and guides, and the head thoroughly washed.

## Removing the Valves

There are various types of lifters used, depending on the design of the valve gear (Fig. 26-1). A lifter tool is designed to lift the valve spring cup clear of the retainer so that the keepers may be withdrawn and the valve released.

When the valves are removed, they should be inserted in a board provided with holes. The holes should be numbered so as to permit the reassembly of the valves in their original position. An inspection of the valve seats and valve faces will determine whether reseating and refacing are necessary.

# VALVE GUIDES

The clearance between the valve guides and the valve stems is very important. Lack of power and noisy valves, in many instances, can be traced to worn valve guides. The intake valve guides should be checked with an intake valve and the exhaust valve guides should be checked with an exhaust valve, because the diameters of the stems are often different.

# REFACING VALVES

Valve refacing should be closely coordinated with the valve-seat refacing operation so that the finished angle of the valve face will

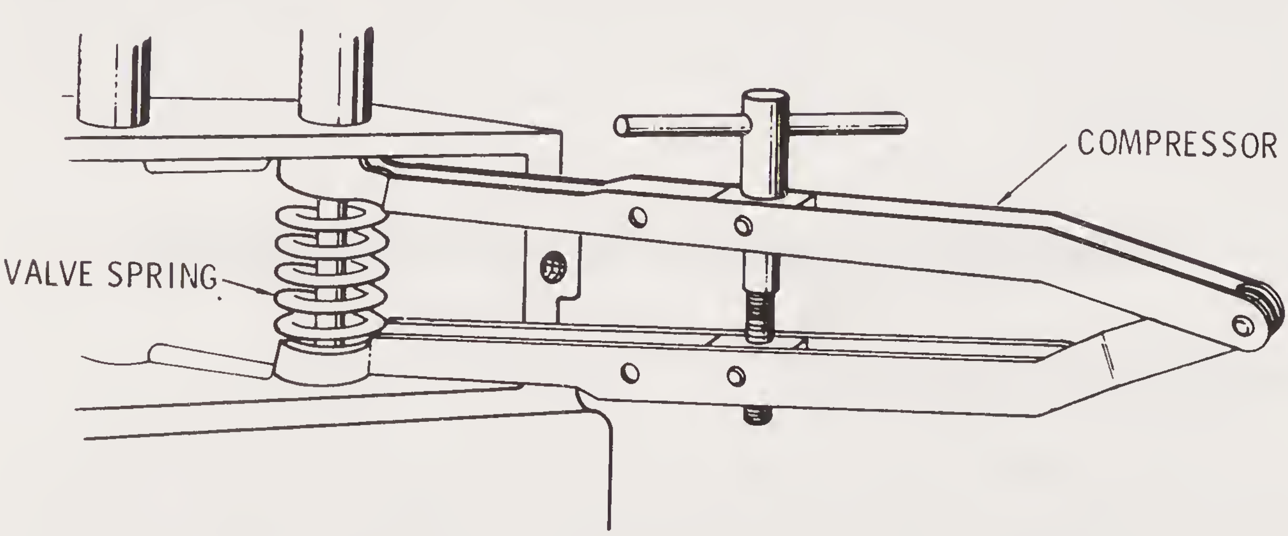



**Fig. 26-1. A typical valve spring compressor tool for flat-head-type engines, showing method of compressing the valve spring to permit removal of retainer.**

match the valve seat. This is important in order that the valve and seat will have a good, compression-tight fit. Be sure that the refacer grinding wheels are properly dressed.

If the valve face runout is excessive, and to remove pits and grooves, reface as necessary. Remove only enough stock to correct the runout and to clean up the pits and grooves. Note that different face angles on the exhaust and intake valves are possible.

After refacing the valves, it is good practice to lightly lap in the valves with a medium-grade lapping compound to match the seats. Be sure to remove all the compound from the valve and seat after the lapping operation. See Fig. 26-2.

## REFACING VALVE SEATS

Inspect the valve seats for cracks, burns, pitting, ridges or improper angle and reseat. During any general engine overheaul it is advisable to reface the valve seats regardless of their condition. If valve guides are to be replaced, this must be done before refacing the valve seats. See Fig. 26-3.

The finished valve seat should contact the approximate center of the valve face. To determine where the valve seat contacts the face, coat the seat with Prussian blue, then set the valve in place. Rotate the valve with light pressure.

It is good practice to lightly lap in the valve with a medium-grade lapping compound after refacing. Remove all of the compound from the valve and seat after the lapping operation.

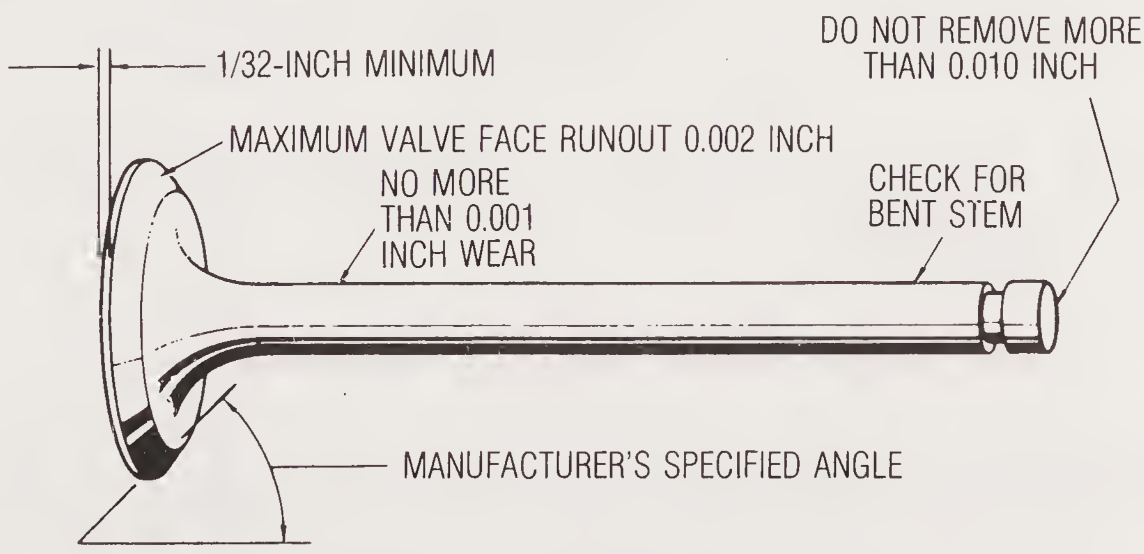



**Fig. 26-2. Critical valve tolerances.**

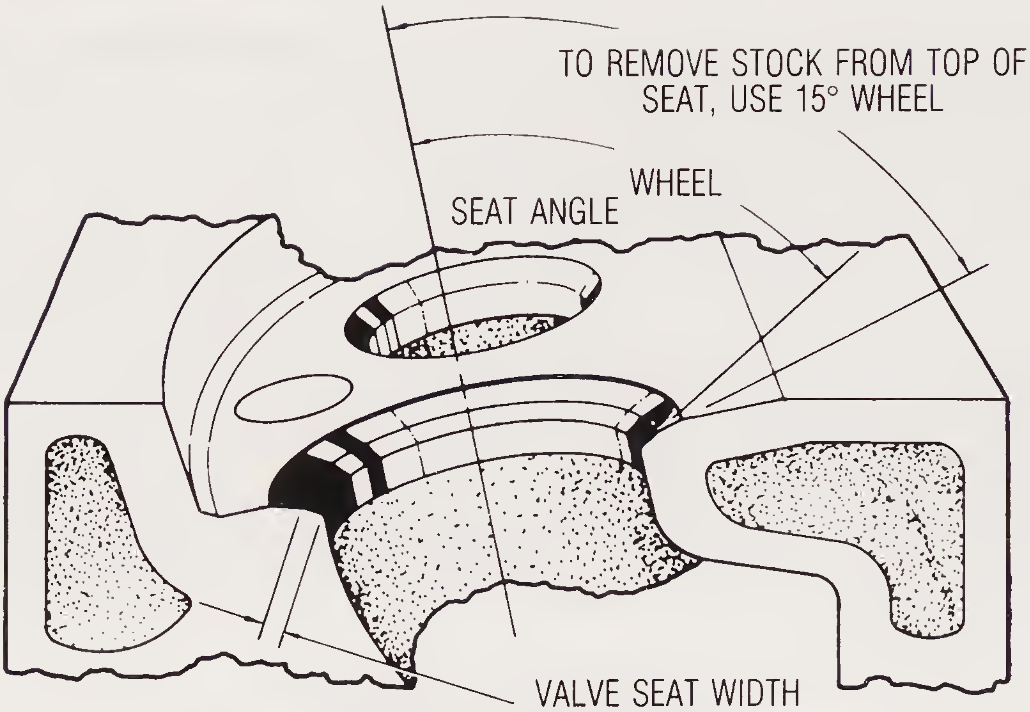



**Fig. 26-3. Intake valve seat refacing.**

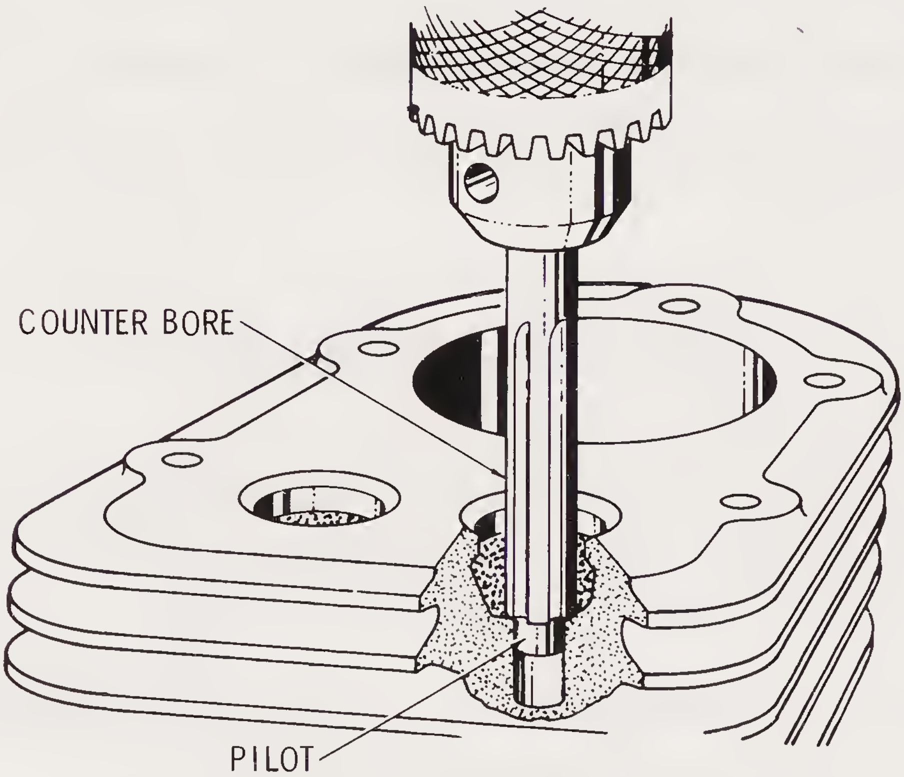



**Fig. 26-4. Method of counterboring to permit installation of replaceable valve guide.**

## REAMING VALVE GUIDES

If it becomes necessary to ream a valve guide in order to install a valve with an oversize stem, always use the reamers in proper sequence. Always reface the valve seat after the guide has been reamed. See Fig. 26-4.

## VALVE SPRINGS

Weak valve springs affect the economy and power of the engine. Therefore, each time the valves of an engine are ground, the valve springs should be checked to be sure they have not been weakened by the heat of the engine.

The springs may be quickly checked by comparing the springs removed to the tension of a new spring having the identical size and characteristics as the original. Any spring that does not match up with the new spring should be replaced. In replacement, use only a spring specified by the engine manufacturer.

One method of checking valve springs for squareness is by means of a steel square and a surface plate as shown in Fig. 26-5. Stand the spring and square on end on the surface plate. Slide the spring up to the square. Revolve the spring slowly and observe the space between the top coil of the spring and the square. If the spring is out of square more than the amount noted, replace it.

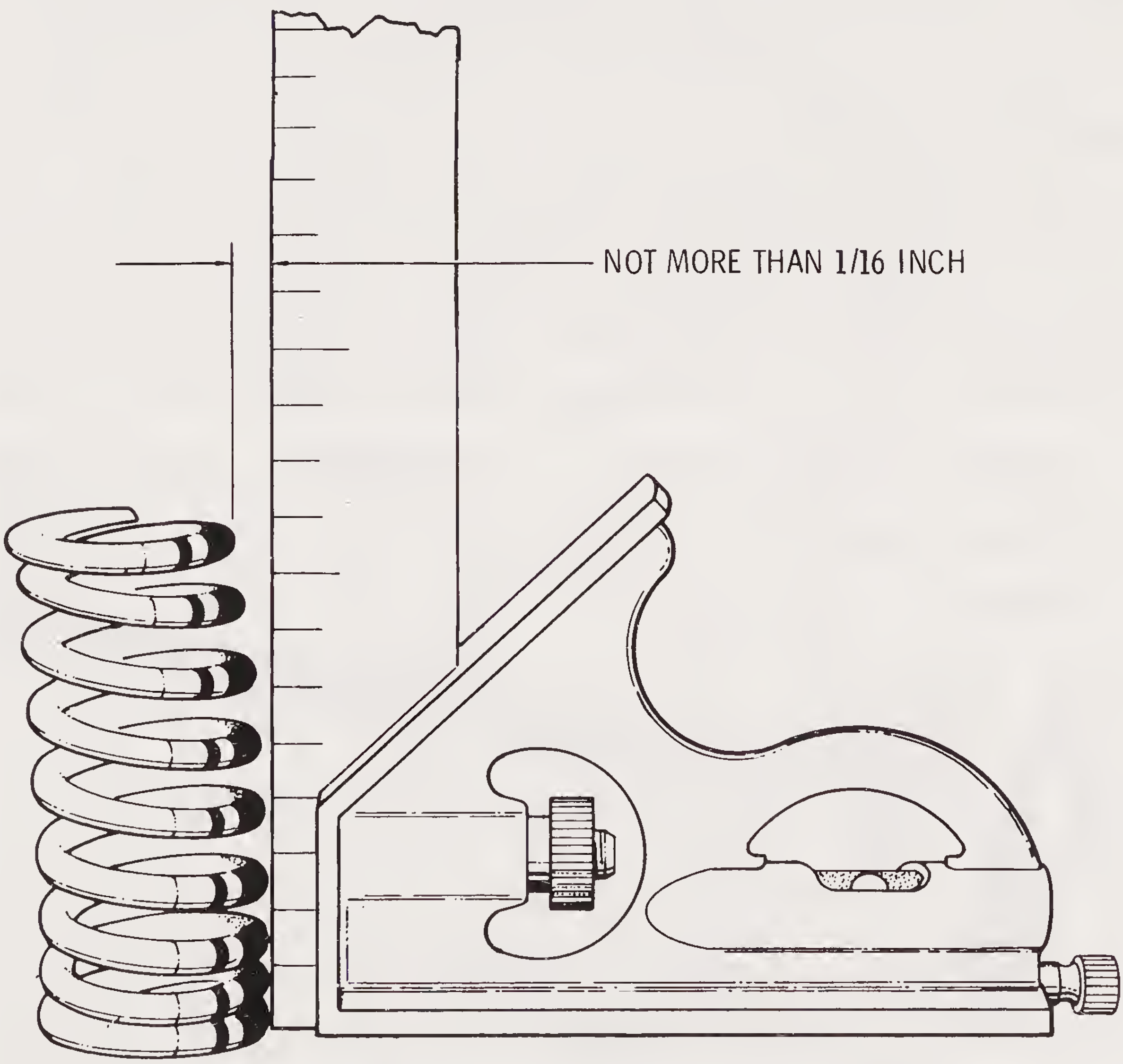



Fig. 26-5. Method of checking valve spring.

Another quick check is to line up all the intake springs together, then all the exhaust springs. If any substantial difference in height is noticed, replace all springs. Weak springs show up more during high-speed performance by limiting top speed, since they allow the valves to "float," or not follow the cams on the camshaft. Weak or broken valve springs must be replaced by the correct spring.

## CAMSHAFT SERVICE

In order to facilitate removal and replacement of camshafts, the usual practice is to make the bearings slightly "tapered," that is, the largest bearing is located at or near the front end of the engine, usually just back of the timing gear. See Fig. 26-6.

When the camshaft is removed, check with a micrometer the bearing dimension for out-of-round. If the journals exceed .001 in. out-of-round, the camshaft should be replaced. Another important inspection operation, when the camshaft is removed from the engine, is to check it for alignment. The most important inspection of a camshaft is visual. Carefully look over all lobes for pitting or rounding of edges. Any camshaft showing even the slightest bit of wear has little operating time left and should be replaced.

If it becomes necessary to replace a press-fit camshaft gear, a sleeve to properly support the gear on its hub is necessary. In replacing the gear on the camshaft, the back of the front journal of the camshaft must be firmly supported in an arbor press. The gear

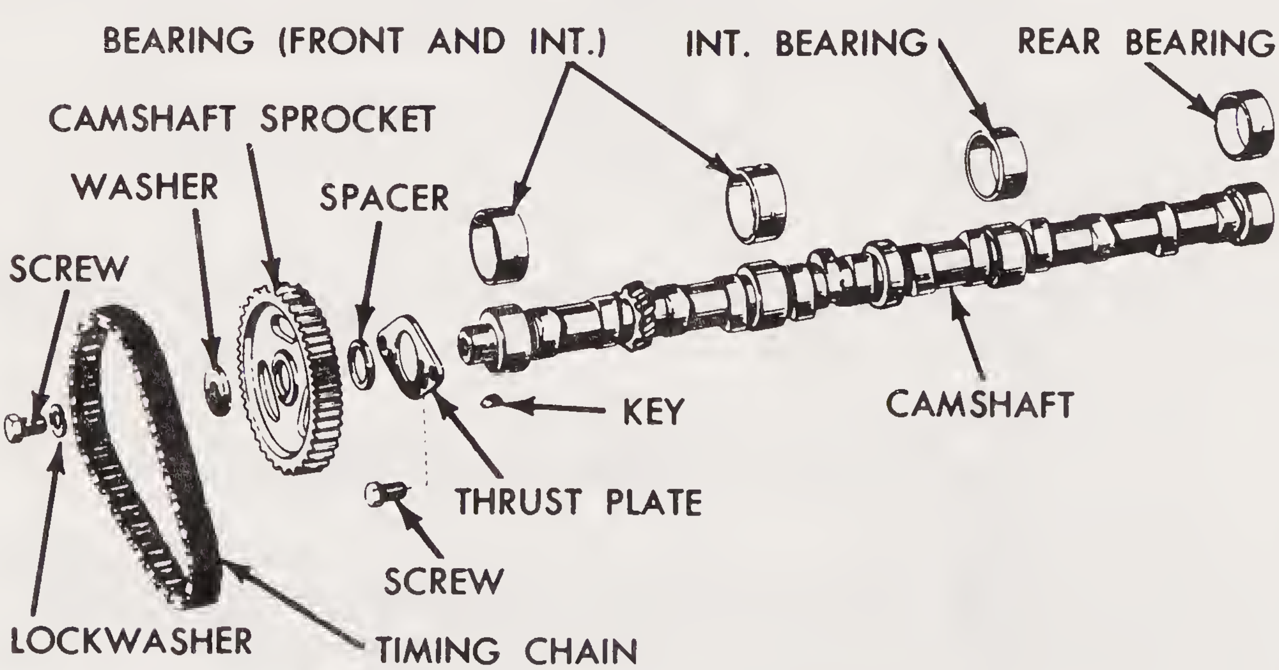



Fig. 26-6. Camshaft and related parts.

is pressed on the shaft far enough so that the camshaft thrust plate has no clearance yet is free to revolve.

If there is an excessive amount of end play in the camshaft, it will be necessary to remove the gear and shaft assembly and press the gear further on the shaft so that the thrust plate is tight yet free to revolve.

When the camshaft and gear are assembled to the engine, it is important that the punch marks on both the camshaft and crankshaft gear be opposite each other as shown in Fig. 26-7. The camshaft will then be in proper position so that the valve will open and close in proper relation to the piston. After the camshaft and the crankshaft gears are in their proper places, check the crankshaft timing gear for runout with a dial indicator. If, after the foregoing checks have been made, runout is noticed, remove gears to be sure that burrs on the shaft and gears are not causing runout. If necessary, replace

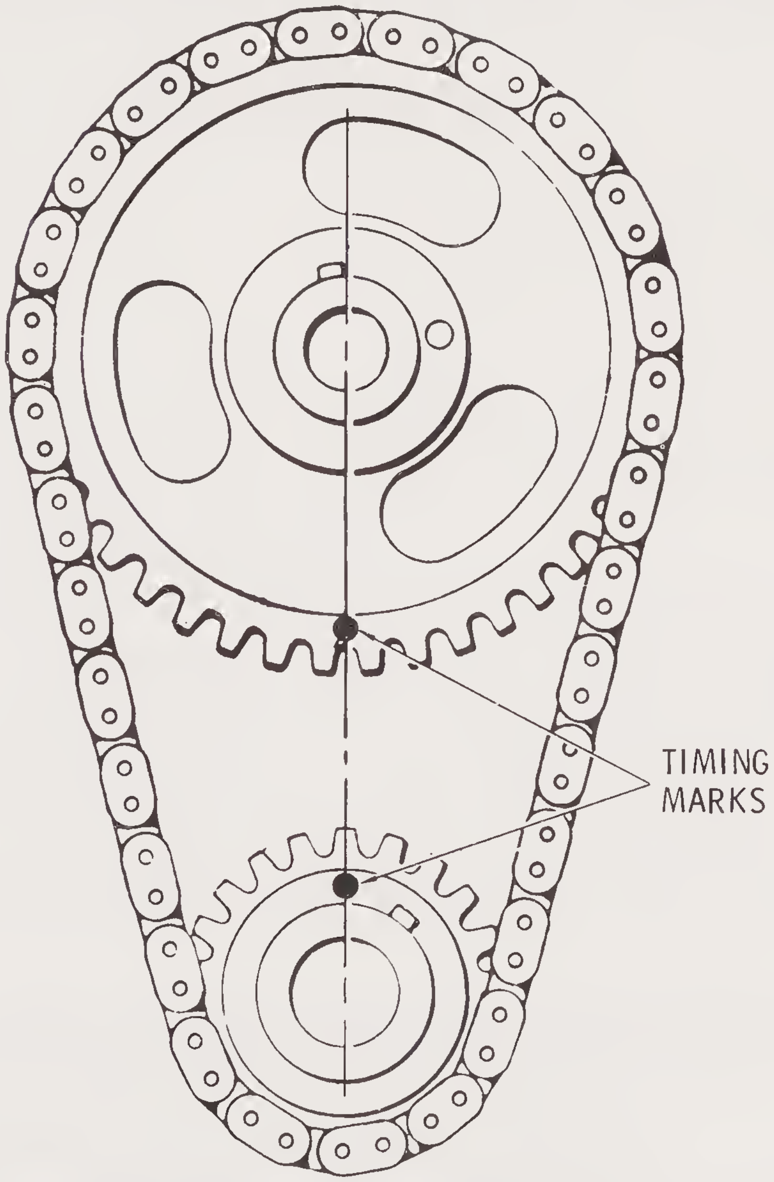



**Fig. 26-7. Typical timing gear marks.**

with new gears. The backlash should also be checked. This check is made with a feeler gauge placed between the teeth in direct gear to gear systems or by rocking the crankshaft to measure tension of the chain.

When replacing a camshaft, the lifters should always be replaced. If the camshaft is found suitable for reinstallation, the lifters should be carefully inspected for wear, pitting or capping and replaced if any of these conditions are noticed.

## OVERHEAD CAM ENGINES

Servicing of an overhead cam engine is essentially the same. The only difference is in the specialized valve-spring compressor sometimes used and the possibility of a flexible cam drive belt in place of a chain. Of course, the location of the camshaft requires it to be removed from the cylinder head before any valve servicing can begin.

CHAPTER 27

# Carburetor and Fuel-Injection System Service

The major portion of carburetor servicing consists of cleaning, inspection and adjustment. After considerable usage, it may become necessary to overhaul the carburetor and renew worn parts to restore it to its original operating efficiency.

Before adjusting a carburetor, the ignition system should receive attention. There should be a good spark and the plugs should have the correct gap. The appearance of spark plugs is a good guide in making carburetor adjustments. For precision, install a new set of plugs of the correct heat range and see that the ignition system is functioning properly. Start the engine and run until normal running temperature is obtained. Shut off the engine and remove plugs.

## CHECKING CARBURETOR OPERATION

Inspect the spark plug insulators for the following:

1. Barely perceptible, light gray—Normal correct operation.

2. Very clean and bleached white—Lean, not enough fuel.
3. Coated with soot or soft carbon; blackish—Rich, too much fuel.

In the absence of carburetor analyzer equipment, the general procedure to be followed will be as outlined according to the type of carburetor. There are four adjustments to the typical carburetor, as follows:

1. Idle speed.
2. Idle mixture.
3. Choke position.
4. Fast-idle adjustment.

## Idle Speed

Idle speed should always be set to the manufacturer's specification. With the engine idling at operating temperature, check to make sure the choke is completely open. All vacuum controls, emission control hoses and air cleaner should be connected. Adjust to manufacturer's specifications using throttle-speed adjustment. On many newer engines, this adjustment is part of the antidiesel solenoid.

## Idle Mixture

Idle mixture adjustment is best made with an exhaust gas analyzer. If not available, follow this procedure: With all vacuum controls, emission hoses and air cleaner connected, and the engine set at the manufacturer's specified idle speed, slowly turn adjustment screws in until a decrease in rpm is noticed; then turn them out until the rpm just stabilizes. Many new carburetors have limited or sealed adjustments. Recheck idle speed when completed.

## Choke Position

The engine must have been off for a minimum of 8 hours before you check choke position. Depress the accelerator once to set the choke. It should be completely closed. Start the engine. The moment the engines fires, the pull-off should partially open the choke.

If the engine stalls immediately after starting, the pull-off is opening the choke too wide. If the engine begins to run rough and heavy exhaust is noticed after the first minute of operation, the pull-off is not opening the choke a sufficient amount. If the engine continues to run smoothly for a minute or more and then begins to run rough with heavy exhaust, the choke is not opening fast enough. If the engine runs smoothly for the first few minutes but stalls when placed in gear or hesitates when the throttle is opened slowly, the choke is opening too fast. In all conditions, the choke should be fully open before the engine reaches normal operating temperature. If adjustments for the above conditions are included on the particular fuel system being serviced, the service manual will give details of the prescribed procedure and adjustment location.

### High-Speed Mixture Adjust

Almost all modern engines, including many used on small engines today, have jet-controlled carburetors that require no high-speed adjustment. If the carburetor does include a high-speed mixture adjustment, it should be accomplished with the throttle set a relatively high rpm following the same procedure used for idle mixture adjustment.

### Fast Idle

Most manufacturers specify a fast idle speed to be set with the engine operating when fully warmed up and with the fast-idle cam in a particular position. If no specifications are available, adjust when the engine is first started cold, at the minimum rpm at which the engine will not stall.

## SERVICING THE CARBURETOR

When overhauling a carburetor, several steps of importance should be performed to assure a good job.

1. The carburetor must be disassembled.
2. The various jet plugs must be removed.

3. Clean all parts carefully in a suitable solvent, then inspect for damage or wear.
4. Use air pressure to clear the various orifices and channels.
5. Replace questionable parts with new ones.
6. Use new gaskets at reassembly.

When checking parts removed from the carburetor, it is at times rather difficult to be sure they are satisfactory for further service. It is therefore recommended that *new* parts be used.

### Disassembly and Assembly of Small Engine Carburetor

A general pictorial idea of the operations involved in the removal and installation of the various small-engine carburetor parts is shown in Figs. 27-1, 27-2, 27-3, and 27-4, which will serve as a guide as to how to do it.

## CLEANING CARBURETOR PARTS

The recommended solvent for gum deposits is denatured alcohol, which is easily obtainable. However, there are other commercial solvents that may be used with more satisfactory results.

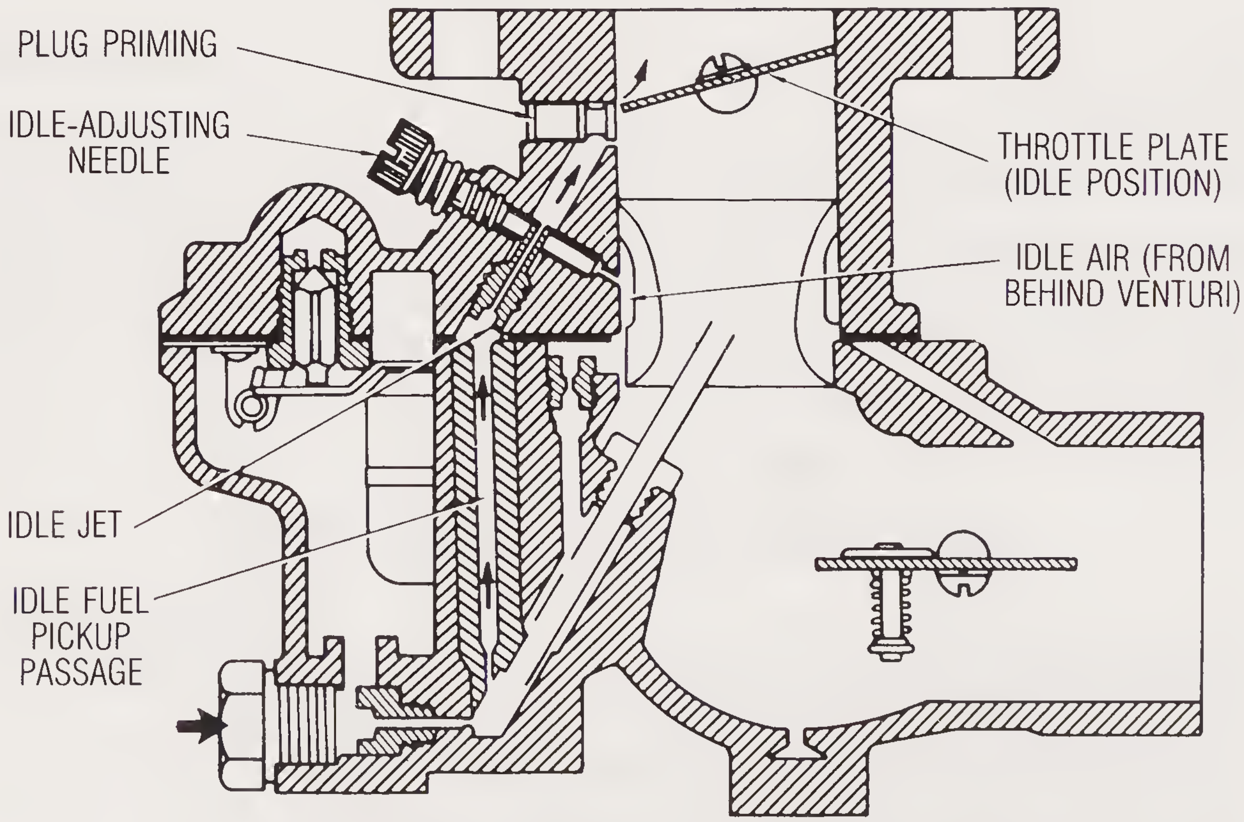



Fig. 27-1. Typical small-engine updraft carburetor.

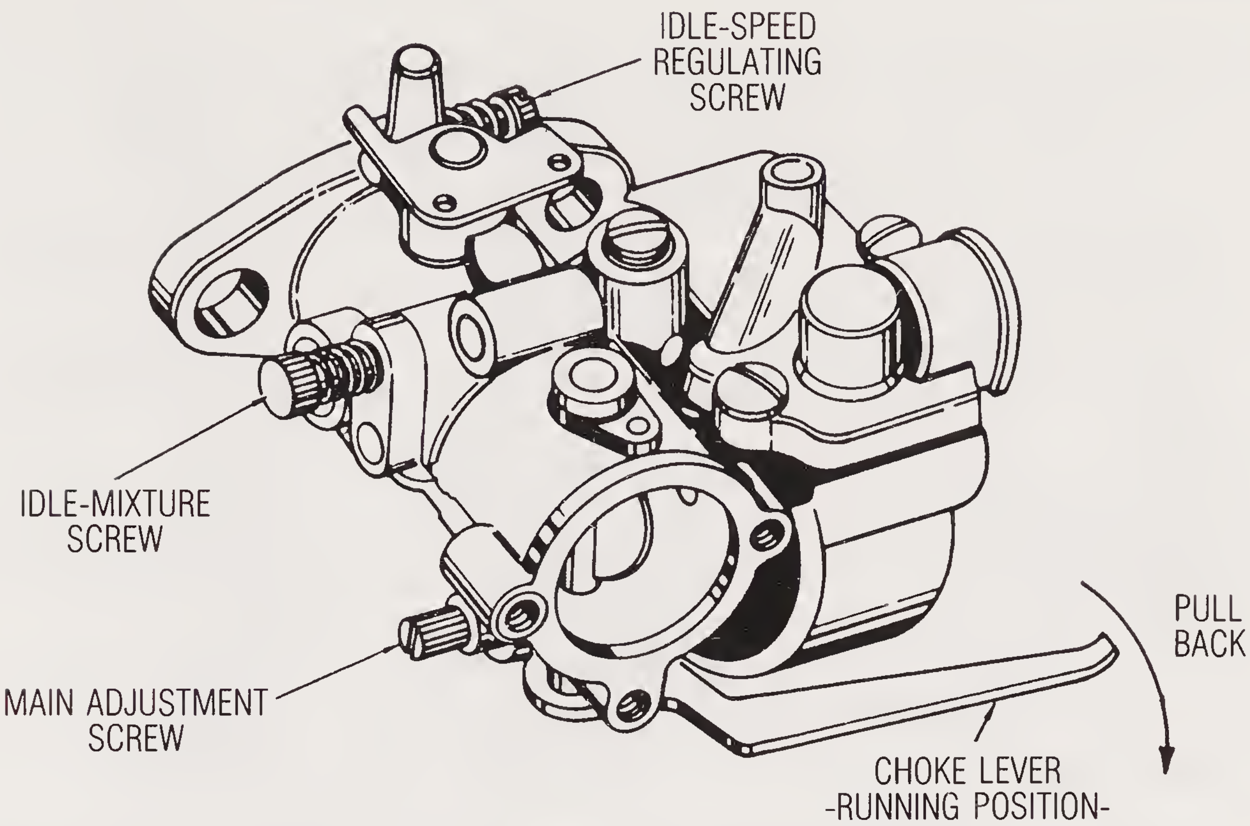



**Fig. 27-2. Location of adjustments on a typical Tillotson carburetor.**

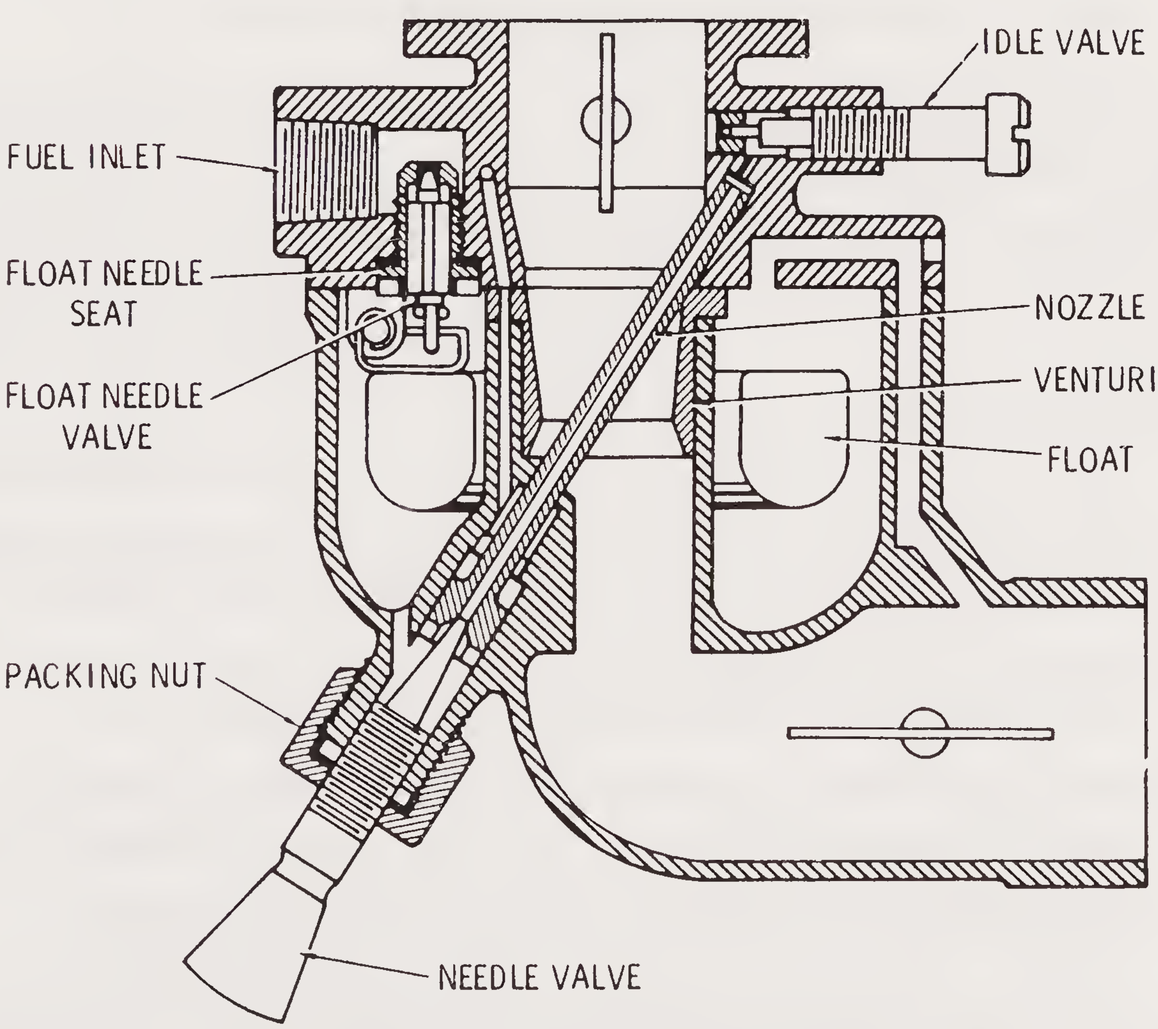



**Fig. 27-3. Typical Briggs and Stratton carburetor with adjustments for both idle and power mixtures.**

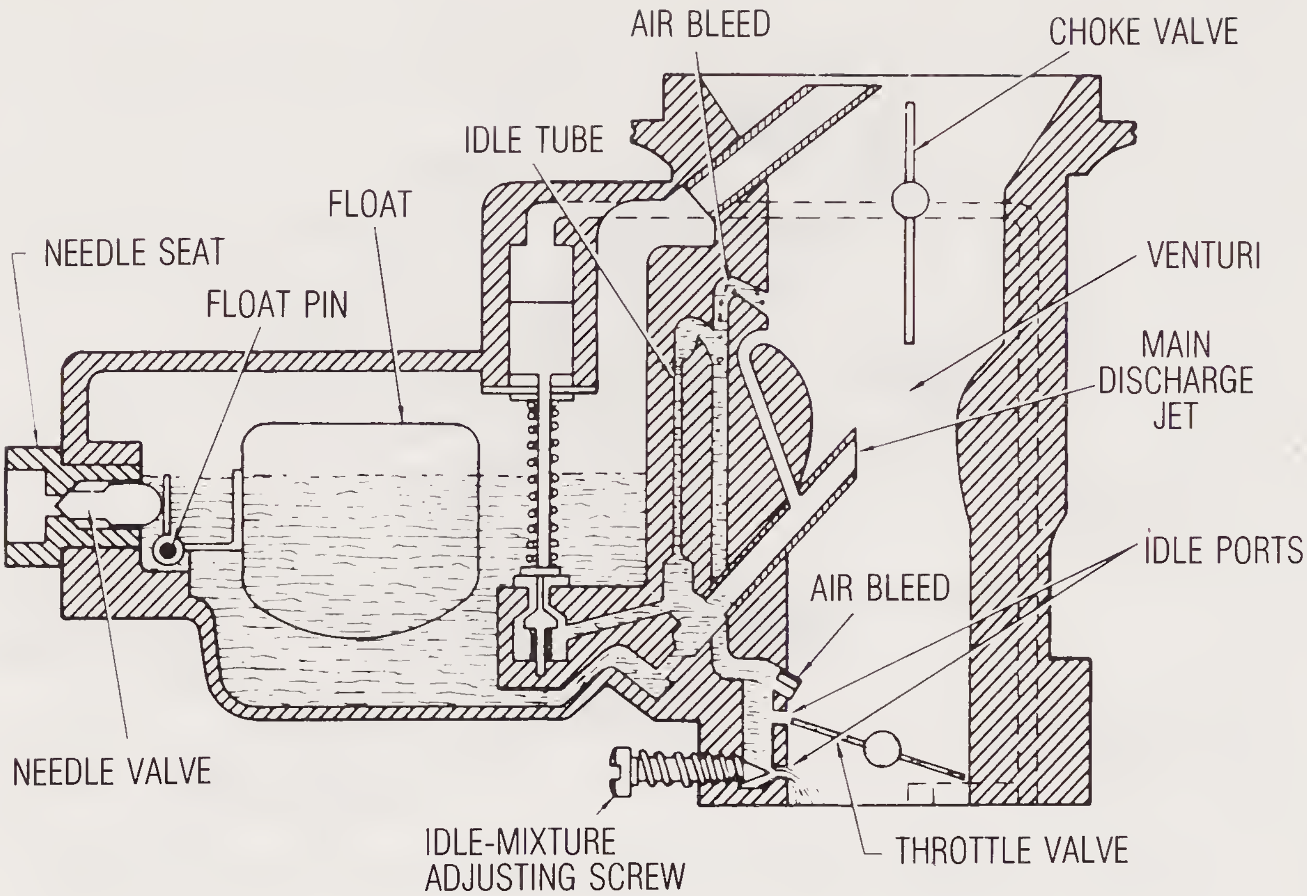



**Fig. 27-4. Typical carburetor illustrating the air-bleed principle.**

**Note**: Never clean jets or orifices with a wire or other mechanical means because they may become enlarged.

*Caution*: If the commercial solvent or cleaner recommends the use of water as a rinse, it should be hot. After rinsing, all traces of water must be blown from passages with air pressure. It is further advisable to rinse parts in clean kerosene or gasoline to be certain no trace of moisture remains.

To remove gum and carbon deposits, a soft brush should be used while the parts are soaking in the solvent. After cleaning, parts should be rinsed in clean solvent and then all passages thoroughly blown out with compressed air.

For inspection and reassembly, proceed as follows:

1. Check the throttle shaft for excessive wear in the throttle body. If wear is extreme, it is recommended that the throttle body assembly be replaced rather than installing a new throttle shaft in the old body. During manufacture, the locations of the idle transfer port and spark advance control ports to the valve are carefully established for one particular assembly. If a new shaft or valve should be installed in an

old worn throttle body, it would be very unlikely that the original relationship of these parts to the valve would be obtained. Changing the port relationship would adversely affect normal operation.

2. Inspect the throttle lever for looseness on the throttle shaft. If the lever is loose, it will be impossible to secure proper idle speed adjustment.
3. Install the idle mixture needle valve and spring in the body. The tapered portion must be straight and smooth. If the tapered portion is grooved or ridged, a new idle needle valve should be used to insure having correct idle mixture control. In making the idle adjustment, do not use a full hand on the screwdriver. Hold the screwdriver with the fingers only to prevent overtightening. Never turn the idle mixture needle valve against the seat.

## CARBURETION

This process may be defined as *the mixing of gasoline in the form of a mist or spray with air in proper proportions to form the fuel charge for a gas engine*. The character of the fuel charge delivered by a carburetor depends on numerous conditions.

Carburetion is affected by:

1. *Fuel pump*—controlling the pressure of the fuel fed to the carburetor.
2. *Air cleaner*—if not clean, will restrict the volume of air taken in by the carburetor.
3. *Carburetor*—including float level control, many variations of jets, venturi air valves, throttle valves, choking devices, etc.
4. *Hot spot*—any device for heating the gas after it leaves the carburetor.
5. *Choke*—the choke affects the volume of air taken in by the carburetor when cold.
6. *Thermostats*—thermostats controlling choke valve, air valve, or other parts of the carburetion system affect the mixture of air and fuel.

7. *Intake manifold*—air leaks in the manifold or gaskets change carburetion.
8. *Muffler*—if the muffler or exhaust pipe is restricted, a portion of the burned gases will remain in the cylinder and only a partial charge of fresh gas will be drawn in.
9. *Emission controls*—if operating incorrectly, will pass air or fumes into the fuel mixture.

# DIAGNOSIS

## Conditions—Possible Causes—Remedies

**Poor performance—mixture too lean**

Possible Causes:

*a.* Damaged, worn, incorrect type or size of main metering jet.
*b.* Damaged tip or bad shoulder on metering rod.
*c.* Vacuum piston operating metering rod worn or stuck.
*d.* Corroded or bad seating power jet.
*e.* Incorrect fuel level.
*f.* Automatic choke not operating properly.
*g.* Worn or corroded needle valve and seat.

Remedies:

*a.* Disassemble carburetor; then replace main metering jet if in questionable condition.
*b.* Remove and disassemble carburetor, clean and inspect metering rod; replace if necessary.
*c.* Disassemble carburetor, and free stuck piston. If piston is badly worn, replace air horn assembly.
*d.* Disassemble carburetor. Clean power jet and channels. If close inspection reveals a faulty seating jet, replacement is recommended.
*e.* Check fuel level in carburetor. Adjust vertical lip of float to obtain correct level as specified.
*f.* Check adjustment and operation of automatic choke. If necessary, replace choke components to correct this condition.

*g.* Clean and inspect needle valve and seat. If found to be in questionable condition, replace assembly and then check fuel pump pressure.

**Poor idling**

Possible Causes:

*a.* Plugged idle tube.
*b.* Plugged idle air bleed.
*c.* Idle discharge holes plugged or gummed.
*d.* Throttle body carbonized or throttle shaft worn.
*e.* Damaged or worn idle needle.
*f.* Incorrect fuel level.
*g.* Loose main body to throttle body screws.

Remedies:

*a.* Disassemble carburetor, then clean idle tube and check.
*b.* Disassemble carburetor, then use compressed air to clear idle air bleed after soaking in a suitable solvent.
*c.* Disassemble carburetor. Use compressed air to clear idle discharge holes after soaking main and throttle bodies in a suitable solvent.
*d.* Disassemble carburetor. Check throttle valve shaft for wear. If excessive wear is apparent, replace throttle body assembly with a new one.
*e.* Replace worn or damaged idle needle with a new unit. Adjust air mixture.
*f.* Check the fuel level in carburetor. Adjust to manufacturer's specification.
*g.* Tighten main body to throttle body screws securely to prevent air leaks. Check for damage to gasket or cracked housings.

**Poor acceleration**

Possible Causes:

*a.* Corroded or bad accelerator pump jet.
*b.* Accelerator pump piston (or plunger) too hard, worn or loose on stem.
*c.* Faulty accelerator pump discharge check valve.
*d.* Accelerator pump inlet check valve faulty.

*e.* Incorrect fuel level.
*f.* Worn or corroded needle valve and seat.
*g.* Worn accelerator pump linkage.
*h.* Automatic choke not operating properly.

Remedies:
*a.* Disassemble carburetor. Clean and inspect accelerator pump jet. Replace jet if in questionable condition.
*b.* Disassemble carburetor. Replace accelerator pump assembly if hard, cracked or worn. Test spring for compression.
*c.* Disassemble carburetor. Use compressed air to clean the discharge nozzle and channels after soaking main body in a suitable solvent. Check the pump discharge valve.
*d.* Disassemble carburetor. Check accelerator pump inlet check valve for sticking or poor seal.
*e.* Check fuel level in carburetor. Low level will cause loss of pump action.
*f.* Clean and inspect needle valve and seat. If found to be in questionable condition, replace assembly and then check fuel pump pressure.
*g.* Disassemble carburetor. Replace worn accelerator pump and throttle linkage, then check for correct position.
*h.* Check adjustment and operation of automatic choke. If necessary, replace choke components to correct this condition.

**Carburetor floods or leaks**

Possible Causes:
*a.* Cracked body.
*b.* Defective body gaskets.
*c.* High float level.
*d.* Worn needle valve and seat.
*e.* Excessive fuel pump pressure.

Remedies:
*a.* Disassemble carburetor. Replace cracked body, being sure main body screws are tight.
*b.* Disassemble carburetor. Replace defective gaskets, then check for leaks. Be sure the screws are tightened securely.

*c.* Check fuel level in carburetor. High fuel level will cause spillage on inclines and turns.
*d.* Clean and inspect needle valve and seat. If found to be in questionable condition, replace complete assembly and then check fuel pump pressure.
*e.* Test fuel pump pressure. If pressure is excessive, replace fuel pump.

**Poor performance—mixture too rich**

Possible Causes:
*a.* Restricted air cleaner.
*b.* Plugged air bleed.
*c.* Leaking float.
*d.* High float level.
*e.* Excessive fuel pump pressure.
*f.* Worn main metering jet or metering rod.

Remedies:
*a.* Remove and clean or replace air cleaner.
*b.* Remove, dissassemble and clean carburetor in suitable solvent.
*c.* Disassemble carburetor. Replace leaking float with a new unit. Check float level.
*d.* Adjust float as described in service manual.
*e.* Check fuel pump pressure. If pressure is in excess, replace fuel pump assembly.
*f.* Disassemble carburetor. Replace worn metering jet or metering rod with a new one of the correct size and type.

## FUEL INJECTION SYSTEM SERVICE

Since most of these systems are electronically controlled by preprogrammed, unserviceable devices, service operations are, for the most part, limited to unit malfunction tests and replacements. Well-equipped service departments utilize special testing devices to determine the proper functions of the system components. However, there are several tests (based on engine operation) that can help to isolate a system's malfunction. When removing and replacing a

component, extra precautions must be taken to keep all parts physically and electrically clean.

**Note:** Before suspecting the fuel injection system for engine malfunction, be sure the ignition system is in proper working order.

## Engine Will Not Start

If the starter rotates the engine but the engine will not start, check for a blown fuel-pump fuse, an open circuit between the battery and ECU, or a faulty jumper harness for the high-pressure fuel pump. Any of these situations could cause the fuel pump not to operate. In addition, the fuel pump itself could be inoperative.

To check and see if any of the above situations are occurring, place the ignition switch to "on" position and listen for the whine of the fuel pump (which should last for about 1 second). If no whine is heard, then check out the above trouble areas. Remove and replace faulty items.

In addition to the aforementioned, other system components can prevent the engine from starting. Check for an open circuit between the ECU and the starter solenoid, a faulty ECU jumper harness or a faulty connection at a sensor. Also check for hampered fuel flow.

If a cold engine will not start, check for open wiring or a bad connection to the engine-coolant temperature sensor. This sensor can be checked with an ohmmeter connected across its terminals. If resistance is greater than specified, the sensor must be removed and replaced.

## Engine Is Hard to Start

If a cool or cold engine has trouble starting, this could be caused by a defective engine coolant sensor. Check for specified resistance between the sensor's terminals with an ohmmeter. If resistance is greater than specified, remove and replace the sensor.

Malfunction of the high-pressure fuel pump, a defective pressure regulator or a faulty throttle-position switch will also cause cool- or cold engine starting problems.

## High Fuel Consumption

This can be caused by a manifold absolute pressure sensor (MAP) hose which has become disconnected or is leaking. The same holds true for the vacuum hoses for either the pressure regulator or the throttle body.

A faulty coolant sensor or air temperature sensor can also cause poor fuel economy. Check for specified resistance between the terminals of each sensor. If resistance is greater than specified, remove and replace the faulty sensor(s).

## Engine Stalls after Starting

Check for an open circuit in the ignition wire between the fuse blocks and electronic control unit (ECU) and also for a faulty connector connection.

If the engine is either cold or warm and stalls after starting, check the condition of the engine coolant sensor or its wiring. Check for specified resistance between the terminals of this sensor with an ohmmeter. If resistance is greater than specified, replace the sensor.

## Rough Idle

Check the manifold absolute pressure sensor (MAP) hose to see if it has been disconnected or if it is leaking or restricted. Also check the system's harness line to the MAP; if this line is defective, replace the entire harness.

A poor electrical connection at any of the injector valves, or a shorted coolant sensor, will also cause rough idling. To check the condition of the coolant sensor, check for specified resistance across its terminals. If sensor resistance is less than specified, it must be replaced.

When the engine is cold, poor electrical connections or open wiring to the air temperature sensor or the coolant sensor will cause idle difficulties. To check the condition of either sensor, check for specified resistance across the sensor terminals. If resistance (for either sensor) is greater than specified, replace the defective unit.

## Prolonged Fast Idle

Check for a poor electrical connection to the fast-idle valve, or an inoperative heating element. Also, the throttle-position switch could be improperly adjusted and/or a vacuum leak could be causing the problem.

## Engine Hesitates during Acceleration

Check the manifold absolute pressure sensor (MAP) hose to see if it has been disconnected or if it is leaking or restricted. Also check the system's harness line to the MAP for condition. If line is defective, replace the entire system harness.

Other causes can be an improperly adjusted or defective throttle-position switch, intermittent speed sensor operation or a faulty electronic control unit connector or jumper harness.

During cold-engine operation, acceleration hesitation can be caused by the exhaust gas recirculation (EGR) solenoid. The solenoid could be stuck open or have a faulty electrical connection.

## High-Speed Performance Inadequate

This can be caused by an improperly adjusted throttle-position switch or a malfunctioning throttle-position switch. Other units that could cause this condition are a defective high-pressure fuel pump, intermittent operation of the speed sensor, a blocked or restricted fuel filter, or an open wire between the electronic control unit and a sensor.

CHAPTER 28

# Electrical System Service

## BATTERY IGNITION SERVICE

The breaker contacts not only serve to open the primary circuit and cause a high voltage spark, but they regulate the length of time that the current flows in the coil. This has a direct effect on the value of the spark at the spark plugs; and, with the higher speeds and compression pressures of modern engines, this affects the power and speed.

The manufacturer's specifications should always be followed when adjusting breaker contacts, to ensure that the proper amount of separation is provided. If contact points are set too close, they will tend to burn and pit rapidly, while points with too much separation will cause ignition failure at high speed.

After considerable use, contact points may not appear smooth and bright, but this is not necessarily an indication that they are not functioning properly and giving good ignition, and they should

not be disturbed as long as proper operation is obtained. See Fig. 28-1.

Should the points become pitted or burned in operation, rub them lightly with a dry oilstone. Points can also be dressed with a clean ignition file without removing them from the distributor.

Oxidized contact points may be caused by high resistance or loose connections in the condenser circuit, oil or foreign materials on the contact surfaces or, most commonly, normal wear. Check for abnormal conditions where burned contacts are experienced.

## Dwell

The contact points in a modern distributor must be adjusted under actual running conditions with a dwell angle meter. By definition, the dwell angle is *the angle of cam rotation through which the distributor points remain closed.* The points must remain closed

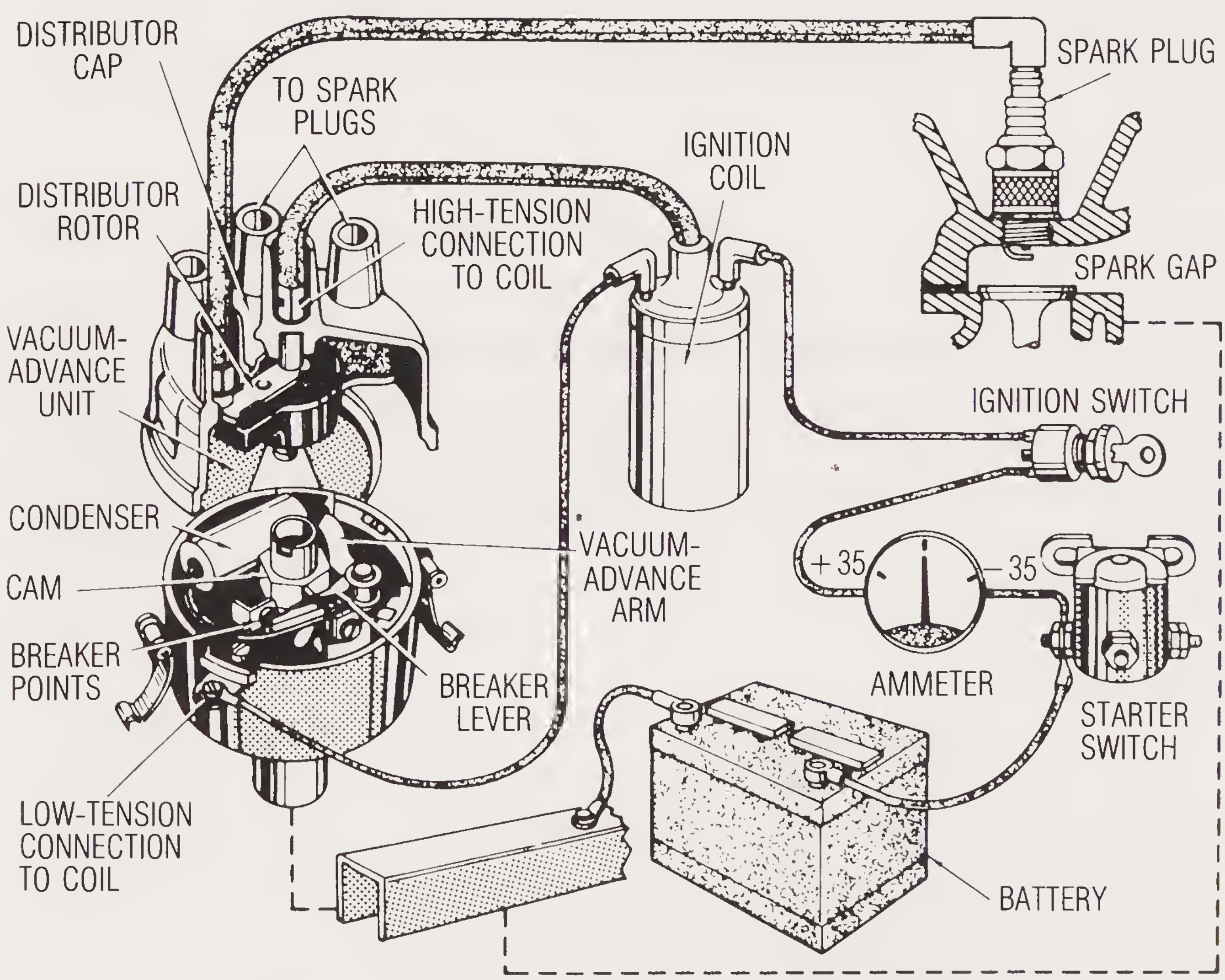



**Fig. 28-1. Typical battery ignition system.**

long enough to ensure saturation and buildup of the ignition coil. Eccentricity and bearing wear will cause variation of dwell angle. See Fig. 28-2.

## Condenser

There are four factors which affect condenser performance, and each must be considered in making condenser tests. They are:

1. Breakdown.
2. Low insulation resistance.
3. High series resistance.
4. Low series resistance.

Low insulation resistance or leakage prevents the condenser holding a charge. A condenser with low insulation resistance is said to be weak. All condensers are subject to leakage, which up to a certain limit is not objectionable. When it is considered that the ignition condenser performs its function in approximately 1/12,000 of a second, it can be seen that leakage can be large without detrimental effects; but it must be considered in making tests.

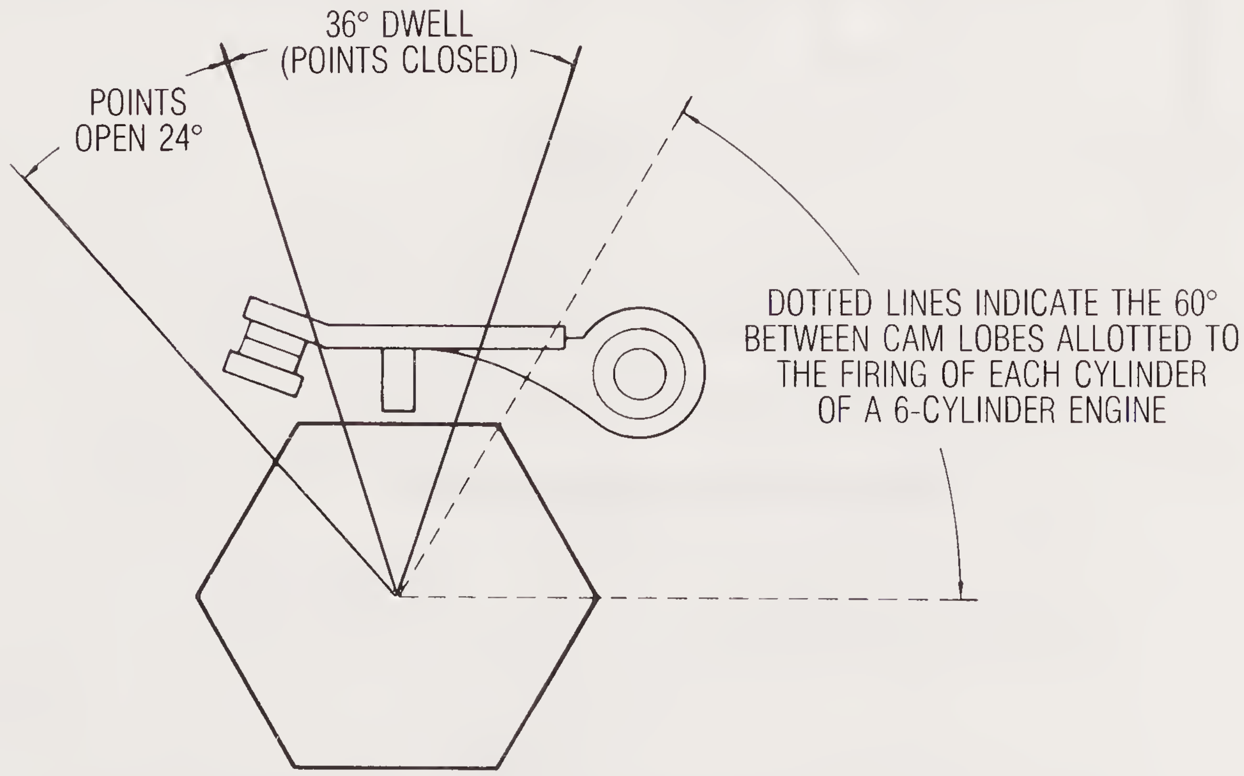



**Fig. 28-2. The meaning of dwell angle.**

## Relationship of Coil to Condenser

The condenser controls the action or output of the coil. Its purpose is to absorb high voltage in the primary winding of the coil, which is essential to proper ignition. The condenser may therefore be considered an integral part of the coil, as without it the coil cannot function.

Obviously, therefore, a condenser with improper capacity or one which leaks is failing to perform its proper function in the operation of the coil, and consequently a coil with an inefficient condenser cannot possibly deliver a spark to the plugs that represent its maximum efficiency. It is important, therefore, that whenever a new coil is installed, the condenser is checked to ensure that it is in good condition. As previously noted, the voltage in the primary part of the coil circuit is very low, the primary having a comparatively small number of turns of heavy wire.

The voltage on the secondary coil circuit, on the other hand, is very high, the secondary having a comparatively great number of turns of fine wire. The voltages in the coil sides vary approximately as the turn ratios, being between 10,000 and 25,000 volts in the secondary and usually 6 or 12 volts in the primary. See Fig. 28-3.

Without the condenser in the primary circuit, the collapse of

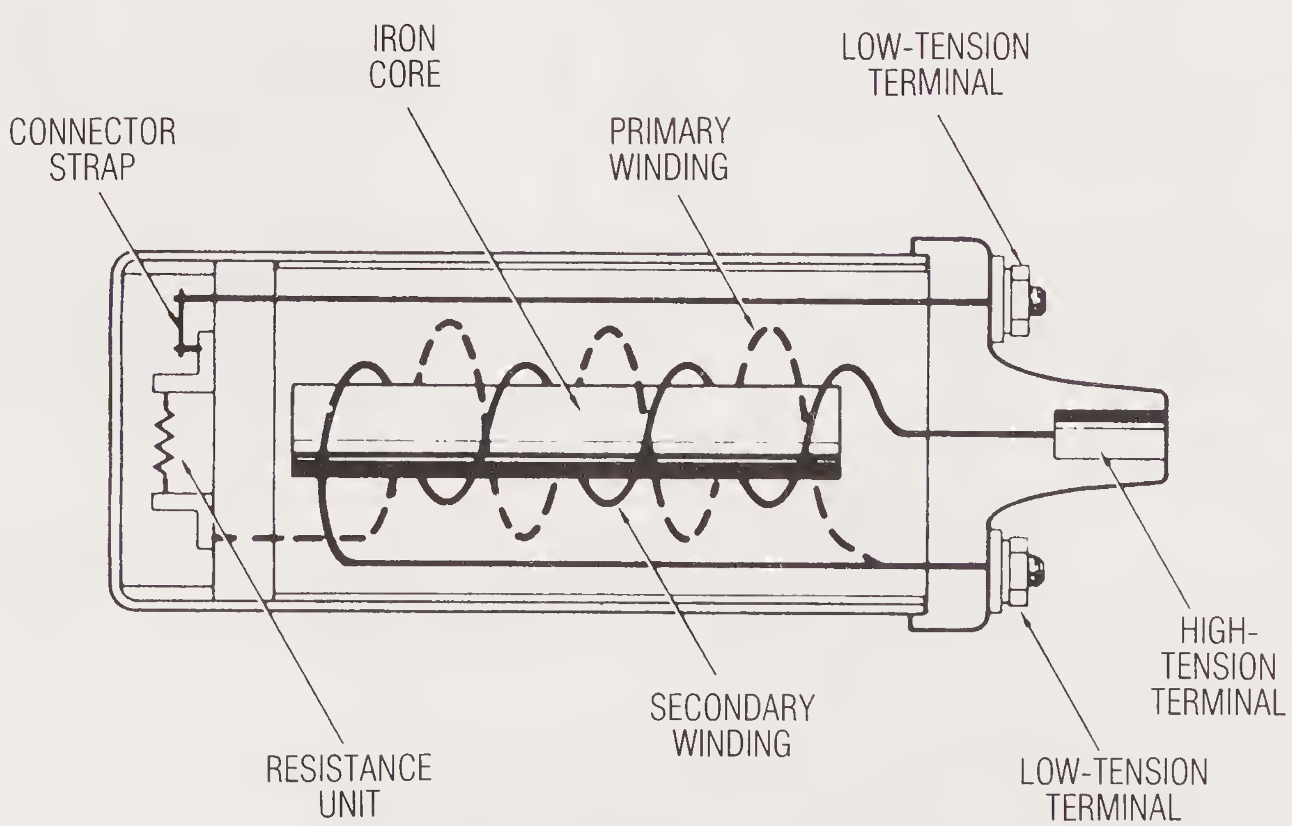



**Fig. 28-3. Ignition coil details.**

the core could be so comparatively slow that the cutting of the lines of force would not be rapid enough to produce the high voltage necessary in the secondary circuit to fire the plugs adequately under high compression. The condenser functions, therefore, are (1) to prevent arcing and (2) to cause a rapid collapse of the magnetic field to induce high secondary voltage.

## Spark Timing

The term *timing* is used to describe the setting of the ignition distributor to ignite the air-fuel mixture within the cylinders at the correct instant. See Fig. 28-4.

When the piston in the cylinder is at top dead center, the air-fuel charge must be ignited. In order to establish this, the ignition distributor must be set (timed correctly) according to the procedure outlined by the manufacturer. Late or retarded timing will cause:

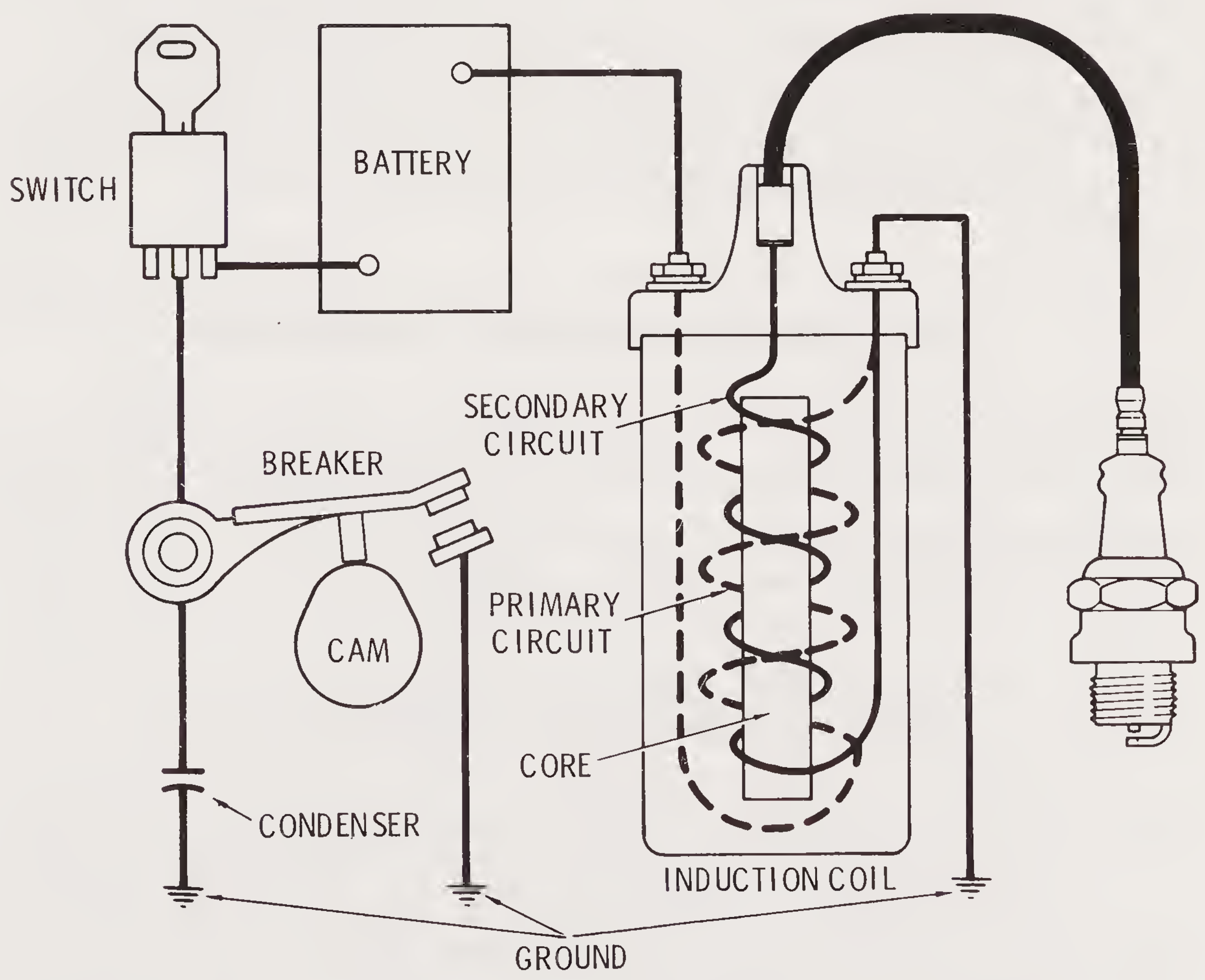



**Fig. 28-4. Schematic diagram showing wiring methods for typical battery ignition system.**

(1) loss of engine power; (2) increased fuel consumption; (3) overheated engine; and (4) hard starting.

Early spark timing may cause: (1) spark knock or detonation; (2) early failure of engine bearings; (3) excessive cylinder and piston wear; and (4) broken pistons. It is therefore important to set or adjust the spark timing as specified by the engine manufacturer.

### Setting Spark Timing

Consult factory specifications for information and instructions as to the markings on the flywheel or balance wheel that are to be used for correct spark timing. The procedure after obtaining the foregoing data is generally as follows:

1. Connect test leads as shown in Fig. 28-5, and hold the power light in line with flywheel or balance wheel markings.
2. Set engine idling at the speed specified by manufacturer. If the engine timing is correct, the ball or degree line as specified by the manufacturer will be opposite the pointer. If timing is not correct, adjust the distributor as directed by engine manufacturer.

## ELECTRONIC IGNITION SERVICE

If the fuel system is known to be properly operational and the engine will not start, the system wiring harness and electric terminals should be checked for tight connections and cleanliness. These could be loose or covered with grease. Also check for a faulty ballast resistor or ignition coil, deteriorated wiring or a faulty control unit.

The electronic distributor (in most systems) is factory preset and requires little or no maintenance. However, the pickup coil in the distributor, if present, could be out of adjustment and cause the system to be inoperative and prevent the engine from starting.

If the carburetor is operating properly, the trouble could be faulty system wiring (as above), loose pickup leads (from the distributor) or a malfunctioning ignition coil.

Engine misses could be caused by dirty or faulty spark plugs, dirty or loosely connected ignition-coil secondary cables, a mal-

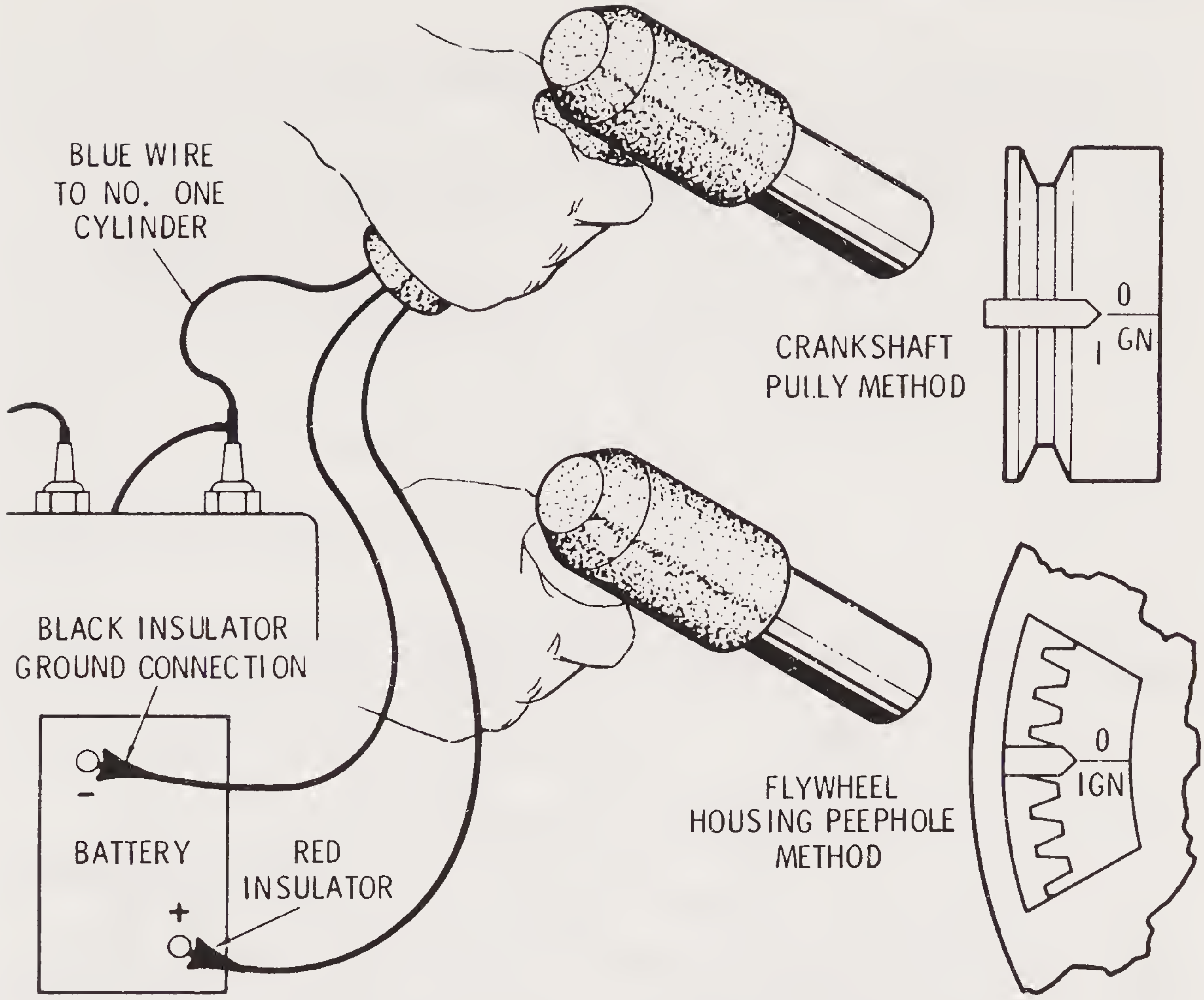



**Fig. 28-5. Arrangement for distributor timing test.**

functioning ignition coil, faulty primary wiring, or an inoperative electronic control unit.

Since the electronic control unit and the ballast resistor cannot be repaired or adjusted, determining whether they are operable (or not) can be accomplished by substituting units known to be in good condition in order to test the system. A malfunctioning ignition switch will also cause the system to become inoperative.

## MAGNETO IGNITION SERVICE

Normally, magnetos are not difficult to service, nor are magneto troubles difficult to diagnose. When a magneto-equipped engine ignition system does not operate properly, a visual inspection will in a great many instances reveal the source of trouble. Particular attention should be given to the spark plugs, distributor, cables, etc., since trouble of this sort may easily be remedied. See Figs. 28-6 and 28-7.

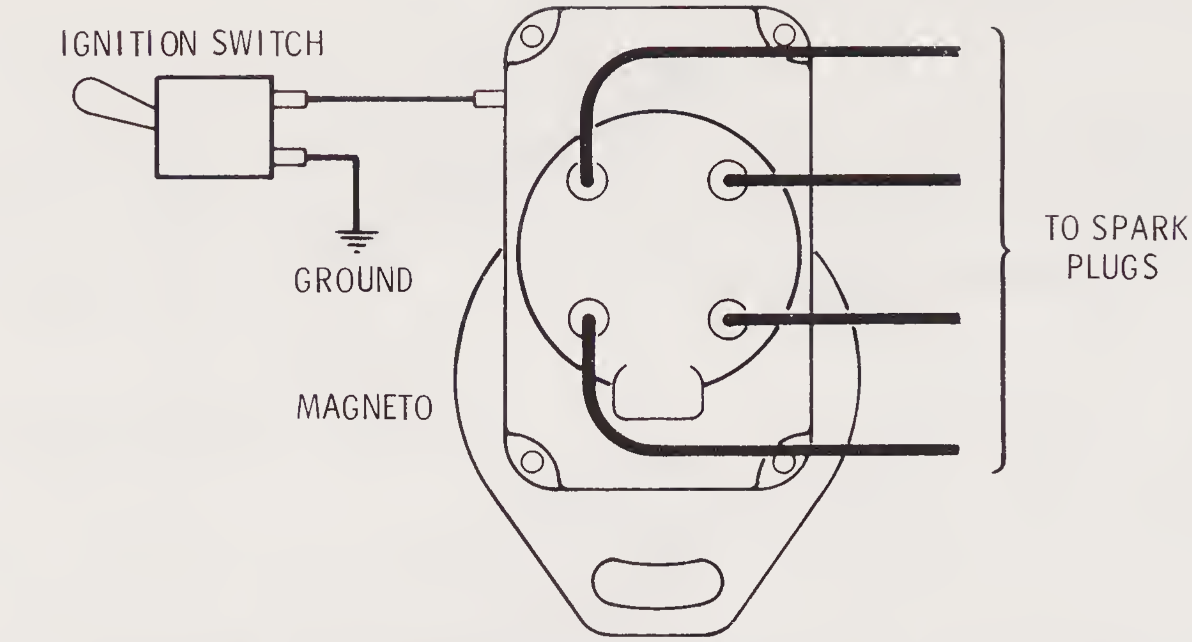



**Fig. 28-6. Wiring diagram of typical magneto ignition system.**

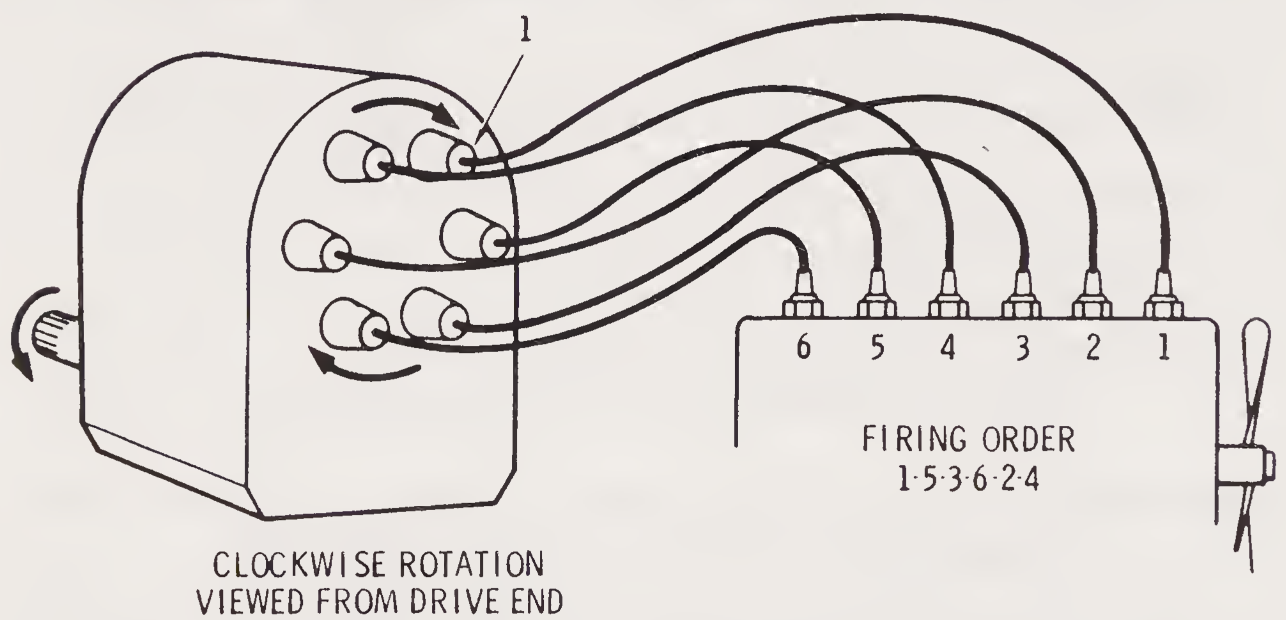



**Fig. 28-7. Magneto spark plug connection.**

If a satisfactory spark is not obtained and it is reasonable to believe that the ignition failure originates in the magneto, a series of simple tests may be made to determine whether the fault lies in the magneto or in other parts of the circuit. In general, when only one cylinder misfires, the fault is in the spark plug. The most common spark plug difficulties are described below.

## Spark Plug Gap Too Wide

Difficulty in starting an engine and missing at low speed are very often due to spark plug gaps being too wide, and as the spark will have a tendency to burn the electrode and thereby gradually in-

crease the gap, it is especially important that the plugs be examined occasionally to see that the gap is not too great. Any difficulty due to this cause may readily be overcome by readjusting the electrodes.

The proper distance between the electrodes of the spark plug varies in different engines, but normally this distance should not be more than 0.035 in. Too wide a gap increases the electrical resistance and interferes with the operation of the engine at low speed.

### Spark Plug Short Circuited

This is usually caused by a cracked insulator or by fouling of the electrodes or insulator. Any of these conditions will cause misfiring by permitting the current to stray away from its intended path.

### Cable Troubles

Misfiring of one cylinder, either continuous or intermittently, may be due also to a chafed or broken cable or a loose cable connection.

The metal terminals of the cables must not come in contact with any metal parts of the engine or the magneto, except those designated as being correct according to the instructions given.

### Irregular Firing

If the cables and spark plugs are in good condition and the firing is still irregular, the trouble is probably in the magneto or the breaker assembly, which should be carefully examined. It is important that the breaker lever move freely and that the contacts are clean and in correct alignment.

### Damaged Insulating Parts

If the distributor plate of the magneto is damaged, it should be carefully examined for possible carbonized tracks or leakage as a result of high-tension flashover.

## Testing Method

With the magneto mounted on the engine, the first step is to ascertain whether the magneto is giving a spark. In this test, the spark plug leads should be detached and the terminal supported ⅛ in. from the metal of the engine while the engine is cranked slowly. If a spark appears, the magneto and the breaker may be regarded as being in good condition.

If no sparks are produced at the spark gaps, inspect the breaker contacts for condition and spacing. Check the magneto switch and primary circuit for high resistance or damaged insultation.

When spare parts are available, the coil or condenser may be checked by the comparison method, provided parts can be readily removed. Install parts known to be in good condition in place of those parts suspected to be defective. If no improvement is found by the checks as outlined and no sparks are produced, the magneto must be removed from the engine for shop service.

In this connection it should be noted that a very common cause of magneto failure is excessive lubrication. A film of oil on the breaker contacts results in arcing, which shortens the life of the contacts. Use clean, light-bodied cylinder oil only sparingly or as recommended by the magneto manufacturer.

## Inspection and Repairs

A convenient method of testing a magneto under operating conditions consists of removing the entire unit from the engine and operating it at various speeds on a suitable test stand. The following procedures are for the more common types of magnetos for industrial engines:

1. Clamp the magneto on the test stand table, fastening it securely so that it cannot slip when driven by the test stand motor.
2. Connect the magneto to the test stand motor, run it at approximately 1000 rpm and check for arcing at breaker contacts. Pinpoint arcing at breaker contacts indicates that the primary circuit is in good condition. Check condenser capacity if breaker arcing is bright and spitting. If no

secondary spark is produced, remove the distributor block and check if sparks jump the safety gap when magneto is turned at operating speed. If spark jumps gap when distributor block is off and does not jump when block is on, renew distributor block.

3. If magneto is still inoperative after previous tests, check the coil using a suitable test instrument.

### Coil Testing

Fundamentally, the coil tester provides a source of primary current intercepted by a built-in breaker to induce a high-voltage current in the secondary winding of the coil to be tested. Primary current is controlled manually by a rheostat in the test unit, giving a definite amperage for each coil unit.

When testing any coil mounted on the armature plate, disconnect the condenser and separate the breaker by a strip of paper. One primary lead from the test unit is connected to the armature plate, with the other connected to the breaker racket. This completes the primary circuit for testing purposes.

If the coil is in good condition and suitable for use, the induced high-voltage current to the spark plugs should be of sufficient strength to consistently spark across the gap on the test unit, with primary current adjusted to amperage specified for the particular coil.

An irregular, seemingly weak or hesitating spark across the gap indicates a weak coil or damp and partially broken-down secondary. Under no conditions should an attempt be made to improve this spark by increasing the primary current. The coil is inoperative if it cannot be made to spark properly on the specified amperage. A completely dead coil is indicated by no visible spark.

## GENERATOR SERVICING

As a general rule, the generator should be inspected and tested at frequent intervals to determine its condition. High-speed operation, excessive dust or dirt, high temperature and operation of generator at or near full output are all factors which increase bearing, commutator and brush wear. See Fig. 28-8.

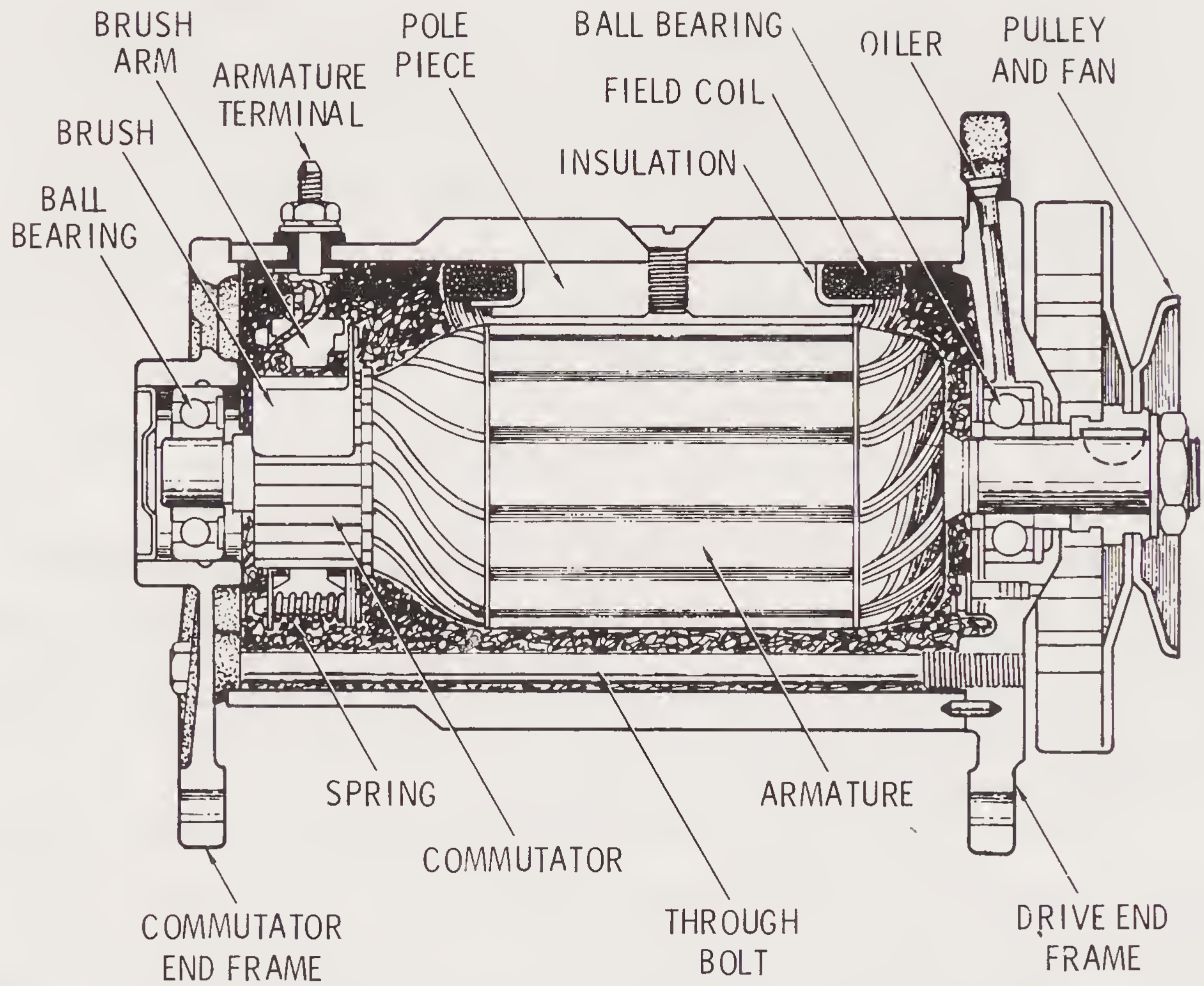



**Fig. 28-8. Sectional view of typical direct current generator.**

When a generator fails to operate properly and it has definitely been determined that the trouble is in the generator and not in some other part of the circuit, the generator should be removed from the engine and taken apart for suitable testing and examination.

## Inspection

The following inspection will disclose whether the generator is in proper condition for service or in need of removal for repairs. Proceed as follows:

1. Using a good light and a mirror, inspect the commutator through the openings in the commutator end frame. Low or irregular output may result if the commutator is coated with grease or dirt, or is rough, out of round or has high mica between the bars. If commutator bars are burned, an open circuit is indicated. Check for proper air circulation. See Fig. 28-9.

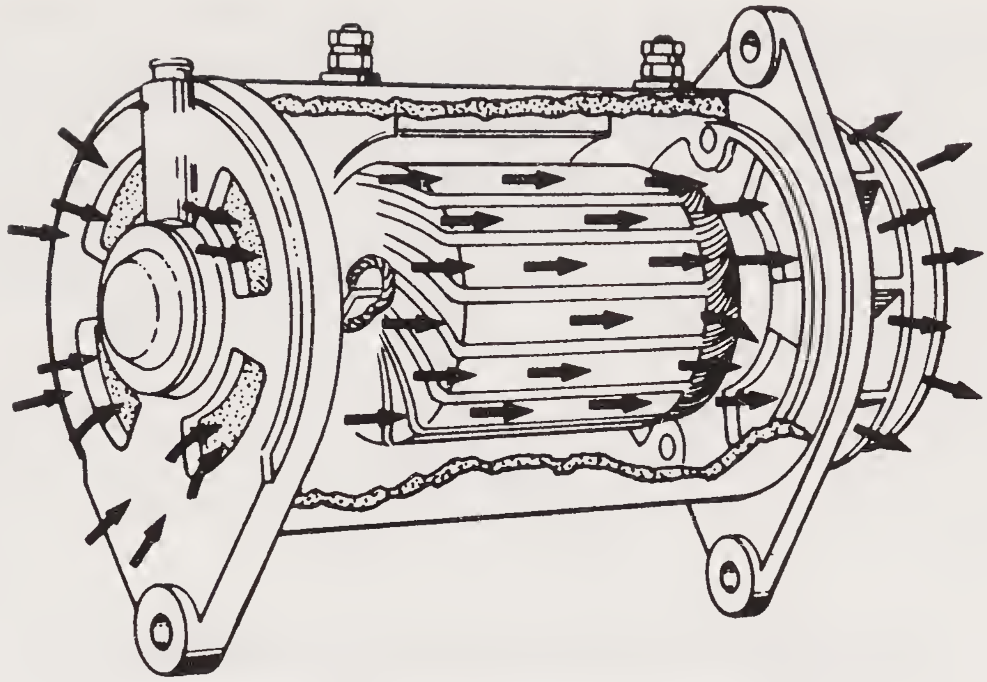


Fig. 28-9. Generator ventilation.

2. Inspect commutator end of generator for thrown solder, indicating the generator has been overheated due to excessive output. Excessive output usually results when the generator field is grounded, either internally or at the regulator. If this is indicated, diconnect the "field" terminal of the generator or regulator and run engine at medium speed. If generator output drops off, the regulator is at fault; but if output remains high, the field is grounded internally in generator. If the field is found to be grounded, the regulator probably will have to be replaced.
3. Check conditions of brushes; make sure that they are not binding in holders and that they are resting on the commutator with sufficient tension to give good, firm contact. Brush leads and screws must be tight. If the brushes are worn down to one-half their original length, the generator must be removed for installation of new brushes.
4. If the commutator or brushes are in bad condition, other than being dirty, they should be replaced. If these parts are only dirty, however, they may be cleaned.
5. Check fan belt for condition and proper tension; make sure that all generator mounting bracket and brace bolts are tight. A loose fan belt will permit belt slippage, resulting in rapid

belt wear and low or erratic generator output. An excessively tight belt will cause rapid belt wear and rapid wear of generator and water pump bearings. If belt requires adjustment, first loosen belt so that generator pulley is free, then check pulley for tightness and check generator bearings for freeness of rotation and excessive side play. Rough or excessively worn bearings should be replaced. See Fig. 28-10.

6. Inspect and manually check all wiring connections at generator, regulator, charge indicator, junction block and battery to make certain that connections are clean and tight.

## GENERATOR REGULATOR SERVICE

Generators, being attached and driven by the engine, run at a speed proportional to the engine rpm. Therefore as engine speed increases and decreases with load and throttle position, generator speed changes and would result in changes in voltage and current output if no control device was included. Accordingly, regulators are necessary to keep the current and voltage within proper limits, as well as to prevent reversal of the current.

Before testing and adjusting the generator regulator, it is advisable to first test the generator output and the charging circuit wiring. If generator output or charging circuit voltage drops are not within normal limits, repairs should be made before testing the regulator.

The following is the general procedure when making tests and adjustments of the *cutout relay*, *voltage regulator* and *current regulator* in the order named:

### Cutout Relay

#### Air Gap.

Disconnect regulator. Measure air gap between armature and center of winding core with the contact points held closed. Bend the spring fingers until both sets of points meet at the same time. If the air gap does not agree with specification, adjust by loosening the two adjusting screws. Raise or lower armature as required.

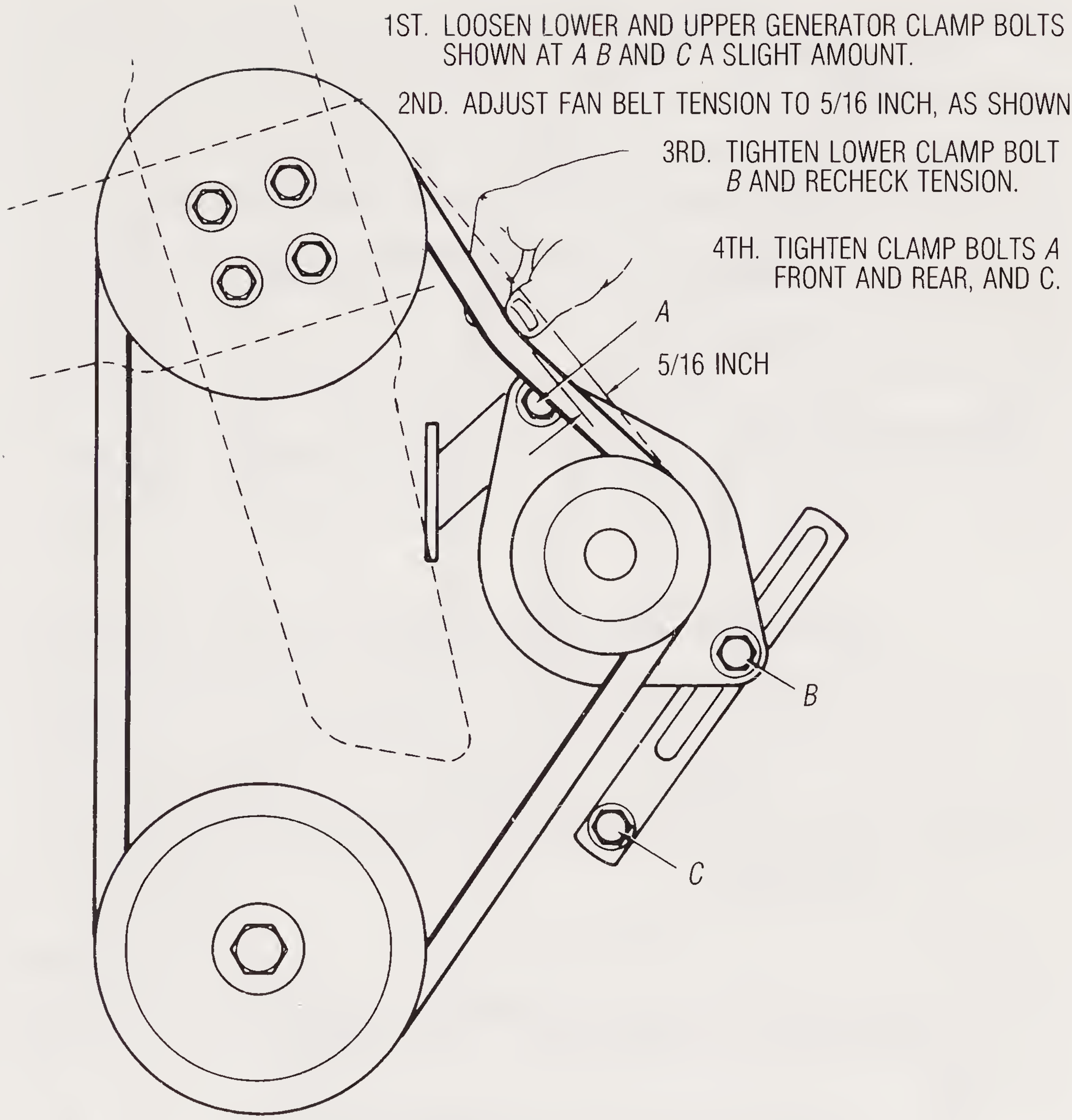



**Fig. 28-10. Method of fan belt adjustment.**

## Point Opening.

Measure point opening. If it does not agree with specifications, bend the upper armature stop until it does.

## Closing Voltage Check.

Connect the regulator to the proper generator and battery (Fig. 28-11). Connect a voltmeter between the regulator "GENERATOR" terminal and the regulator base. Connect an ammeter between the battery and the regulator "BATTERY" terminal. Slowly increase the generator speed until the points close. If the closing voltage is not according to specifications, bend the spring post until it is.

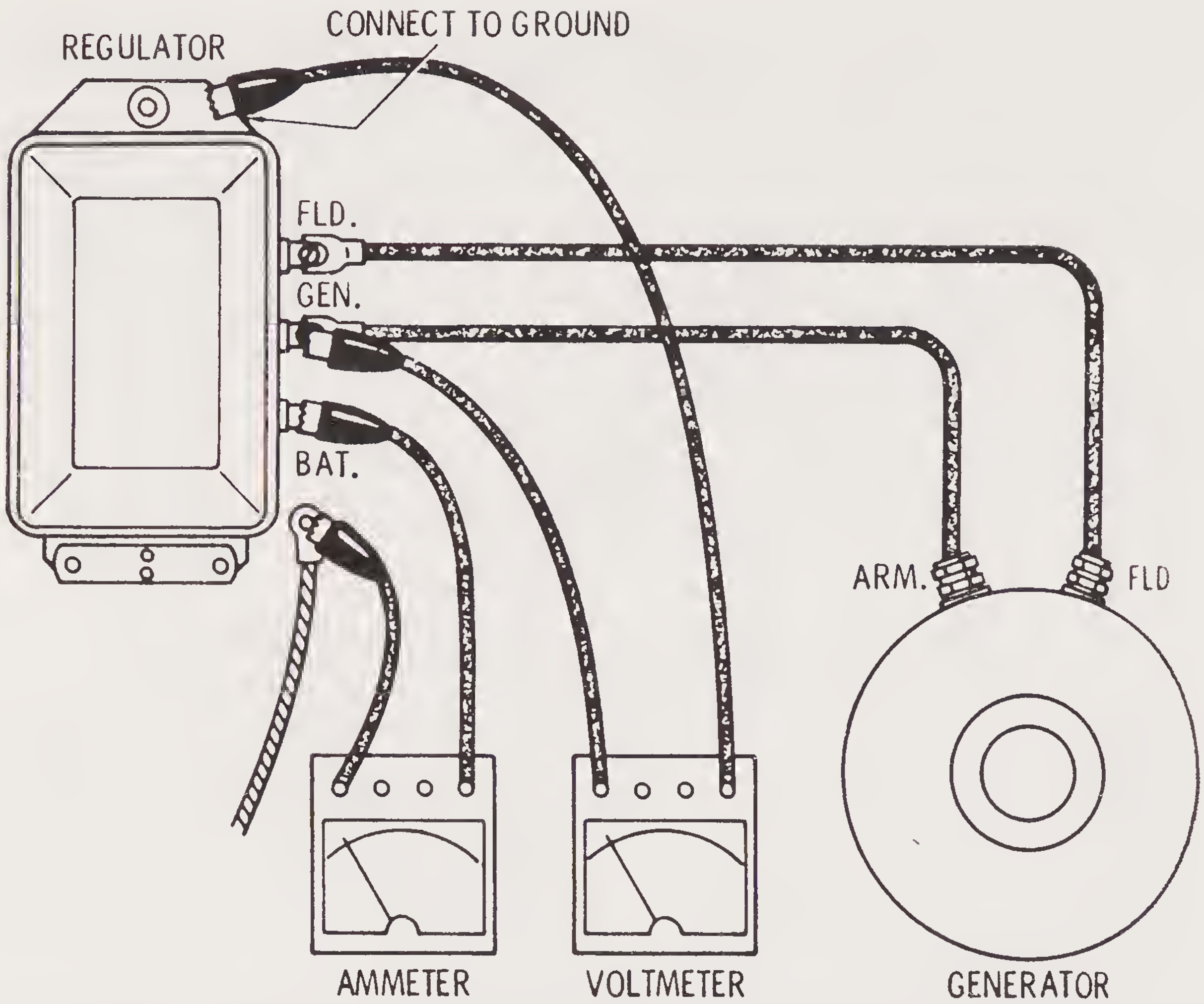



**Fig. 28-11. Wiring diagram illustrating connections for cutout relay adjustment.**

Decrease the generator speed and note the reverse current necessary to open points. If not according to specifications, adjust by changing the air gap. Increasing the air gap lowers reverse current setting.

## Voltage Regulator

### Voltage Setting, Fixed-Resistance Method.

Disconnect the lead from the battery terminal. Connect a test voltmeter and a fixed resistor from the battery terminal to the regulator base. With regulator at operating temperature, run the generator at charging speed and note the voltage setting. If the setting does not agree with specifications, adjust by bending down one spring hanger until it does. Bending the hanger down increases the setting; bending the hanger up lowers the setting. Confine the adjustment to one spring, unless regulator is badly out of adjustment.

For complete adjustment, remove the second spring. Connect

a voltmeter from the "GENERATOR" terminal to the regulator base. Open the voltage regulator points by hand and increase the generator speed until the voltmeter reads approximately one-half the specified operating voltage (open circuit). This establishes the approximate generator speed at which adjustment should be made. Let the points close and adjust the first spring hanger to one-half the total voltage setting. Install the second spring. Connect the voltmeter and resistance as illustrated. Complete the adjustment of the second spring hanger (without changing the first spring hanger) until the correct voltage setting is obtained. After each change of setting, check the adjustment by replacing the cover and reduce the generator speed until the points open; then increase the speed until the points close.

**Voltage Setting, Variable-Resistance Method.**
Connect an ammeter and a ¼-ohm variable resistor between the battery and the "BATTERY" terminal, as illustrated in Fig. 28-12. Connect a voltmeter between the "BATTERY" terminal and the regulator base. Operate the generator at medium speed. If less than

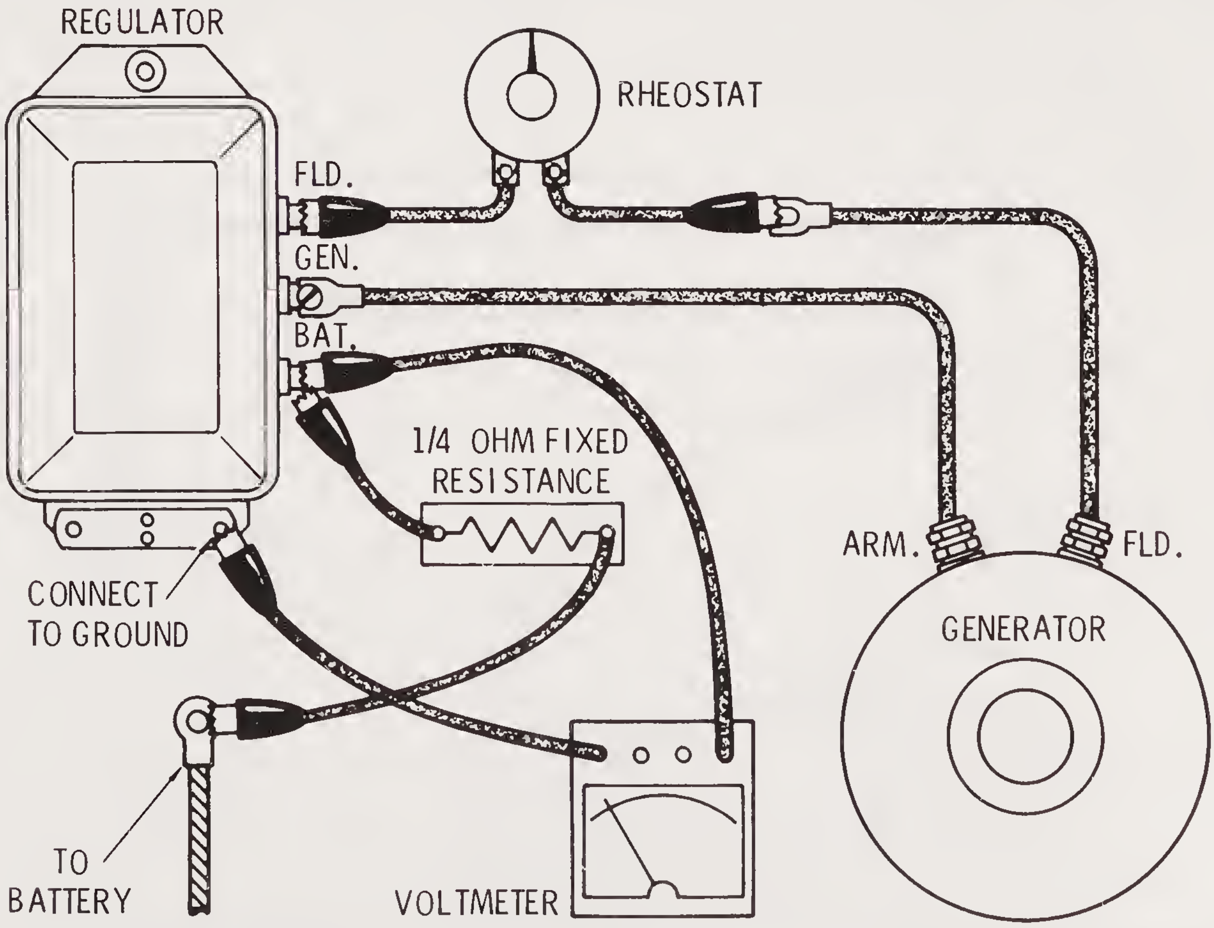



**Fig. 28-12. Wiring diagram illustrating connections for voltage regulator adjustment.**

8 amperes are obtained, turn on all lights and accessories to permit higher output. Increase the variable resistor setting until the current output is reduced from 10 to 8 amperes. Cycle the generator and note the setting. Adjust as in the fixed-resistance method.

### Air Gap.

Disconnect the regulator. Open points by hand. Release the armature slowly until the points touch, then measure air gap. If not according to specifications, adjust by loosening the two mounting screws and raise or lower the contact brackets as required.

## Current Regulator

### Current Setting.

Connect the regulator to generator and battery. Remove regulator cover and connect jumper across voltage regulator points. Connect ammeter as indicated (Fig. 28-13). With regulator at operating temperature, turn on all lights and accessories. Run generator at medium speed and note the current setting. If not according to spec-

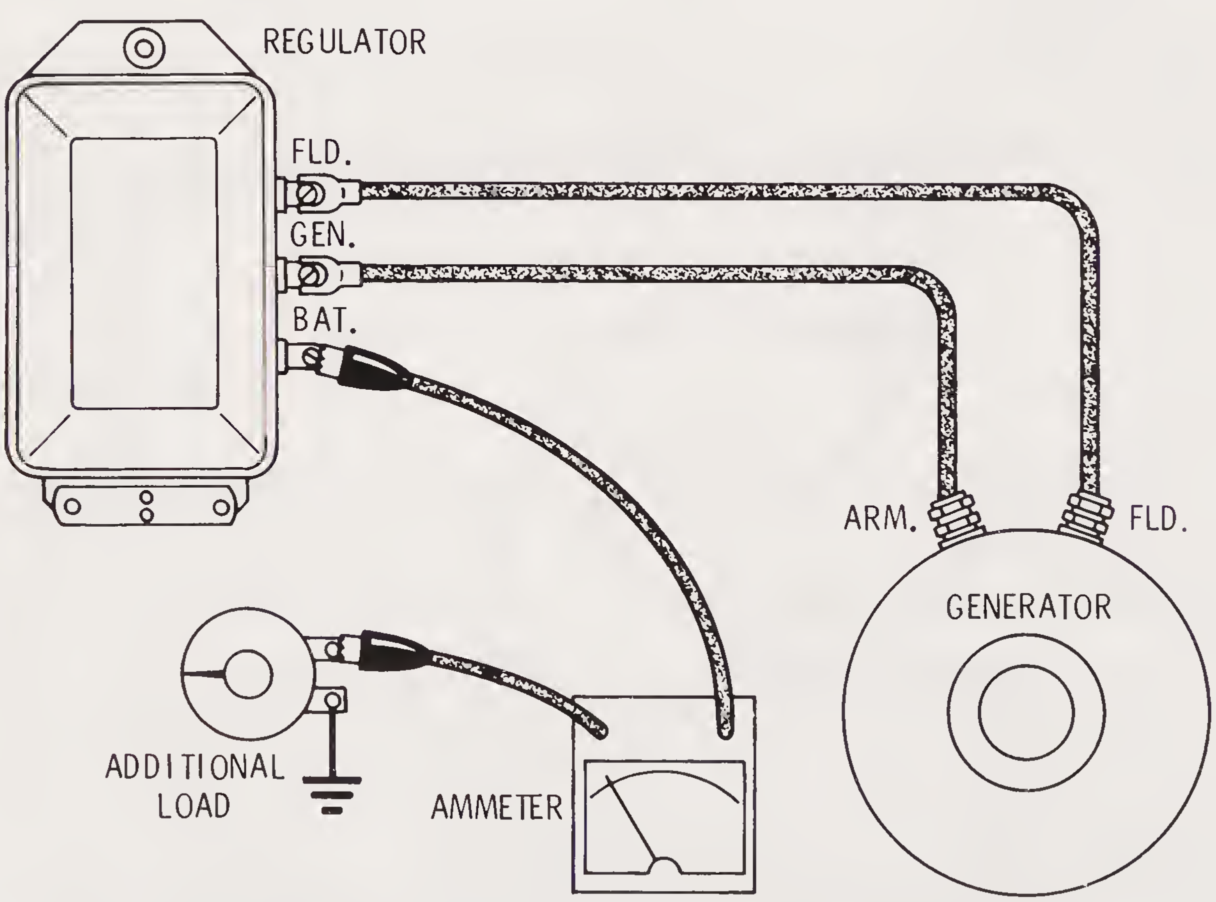



**Fig. 28-13. Wiring diagram illustrating connection for current regulator adjustment.**

ifications, adjust by bending the spring hanger. Confine the adjustment to one spring, unless regulator is completely out of adjustment.

For complete adjustment, remove one spring and adjust remaining spring hanger to one-half the specified setting. Reinstall the first spring and adjust its spring hanger to the full current setting.

### Air Gap.

Disconnect the regulator. Open points by hand. Release armature slowly until points just touch, then measure air gap. If not according to specifications, adjust by loosening the two contact mounting screws and raise or lower contact bracket as required.

## ALTERNATOR SERVICING

Like a generator (preceding), an alternator should be frequently inspected and tested. A battery and charging-circuit tester (there are various commercial units) is used for testing in accordance with instructions supplied with the particular unit. If alternator output is low or erratic, check fan belt and external wiring as previously explained for a generator. If this fails to locate the trouble, the alternator must be disassembled.

After disassembling the alternator (Fig. 28-14), you should perform the same basic inspections and tests as used for the generator.

1. Check the slip rings and brushes for wear. Although they handle a very small amount of electricity compared to a generator, they must still be clean and make good contact for proper operation.
2. The rotor may be checked visually and with an ohmmeter. The reading taken between slip rings should be very low and should read open from the slip rings to the shaft.
3. The stator may also be checked visually and with an ohmmeter. The reading taken between any two terminals should be low and should read open to the case.
4. The diodes can be checked individually with an ohmmeter for low resistance in one direction, very high in the reverse direction.

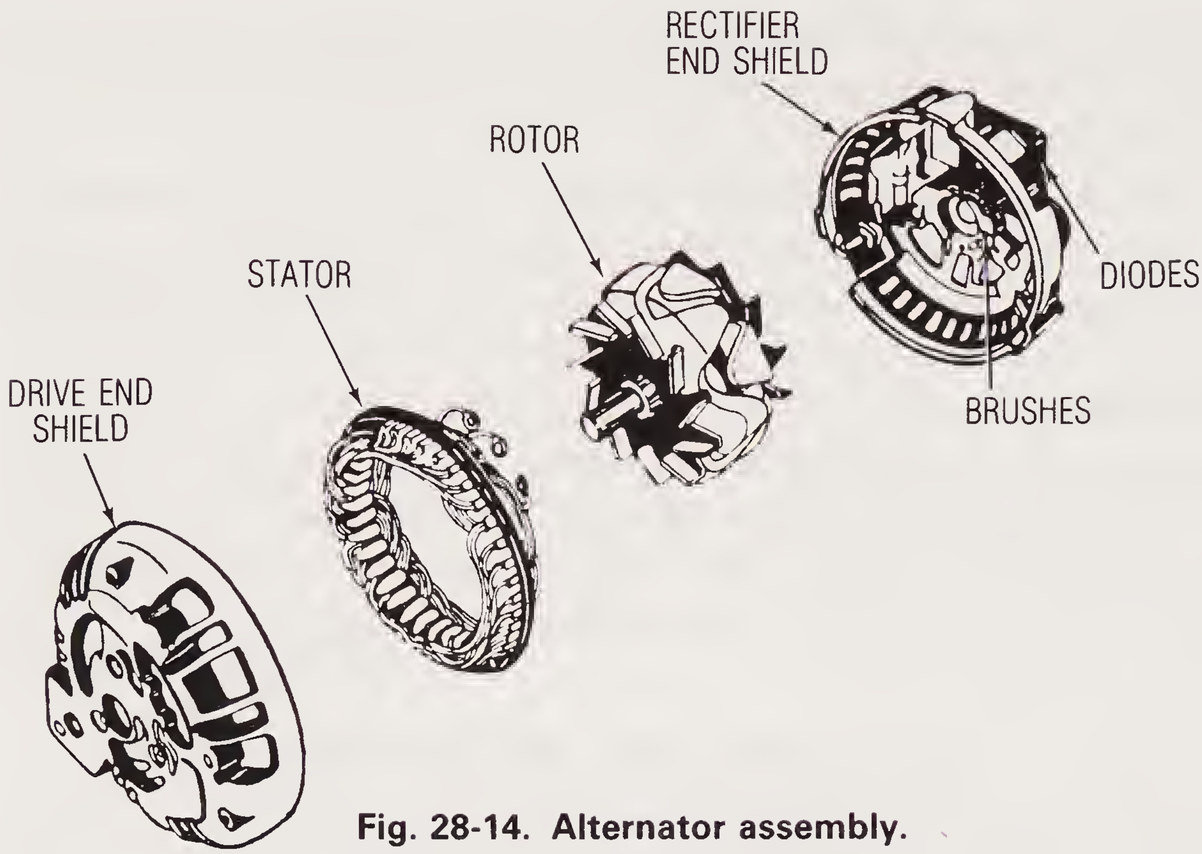



**Fig. 28-14. Alternator assembly.**

5. Of course, belts, pulleys and wiring should always be tested first.
6. Since almost all systems utilizing alternators use solid-state electronic regulators, no adjustment is necessary and the manufacturer's procedure should be followed when testing.

## STARTING-MOTOR SERVICE

The starting system consists of the *battery, starting switch* and *starting motor.* The battery supplies the energy and the switch completes the circuit, allowing this energy to flow to the starting motor. The motor then delivers mechanical energy and does the actual work of cranking the engine. Because of its action in cranking the engine, the starting motor is also called the *cranking motor.*

The starting-motor assembly consists of motor, drive assembly, shift lever and solenoid switch. When the solenoid is energized, the starter armature spins, feeding the pinion on the threaded sleeve (or forcing it forward with a magnetically operated mechanism) until it meshes with the flywheel gear.

The sudden shock of meshing is absorbed by the drive spring. After the engine starts, the flywheel ring gear turns the starter

pinion faster than the armature. At a predetermined speed the gear is released and forced back along the sleeve threads to its normal position.

## Locating Troubles in Starting Motor

In many respects, a starting motor is similar to a generator, and the inspection for location of troubles is also similar. Starting-motor action is indicative to some extent of the starting-motor condition. A starting motor that responds readily and cranks the engine at normal speed when the control circuit is closed is usually in good condition.

If the motor does not develop rated torque and cranks the engine slowly, or not at all, check the battery, battery terminals and connections, the ground cable and the battery-to-cranking-motor cable. Corroded, frayed or broken cables should be replaced, and loose or dirty connections corrected. The magnetic switch should be checked for burned contacts and the contacts replaced, if necessary.

If there are burned bars on the commutator, it may indicate open-circuited armature coils, which prevent proper cranking. Inspect the soldered connections at the commutator riser bars, resolder these connections and turn down the commutator as necessary. See Fig. 28-15 for a typical starting-motor circuit.

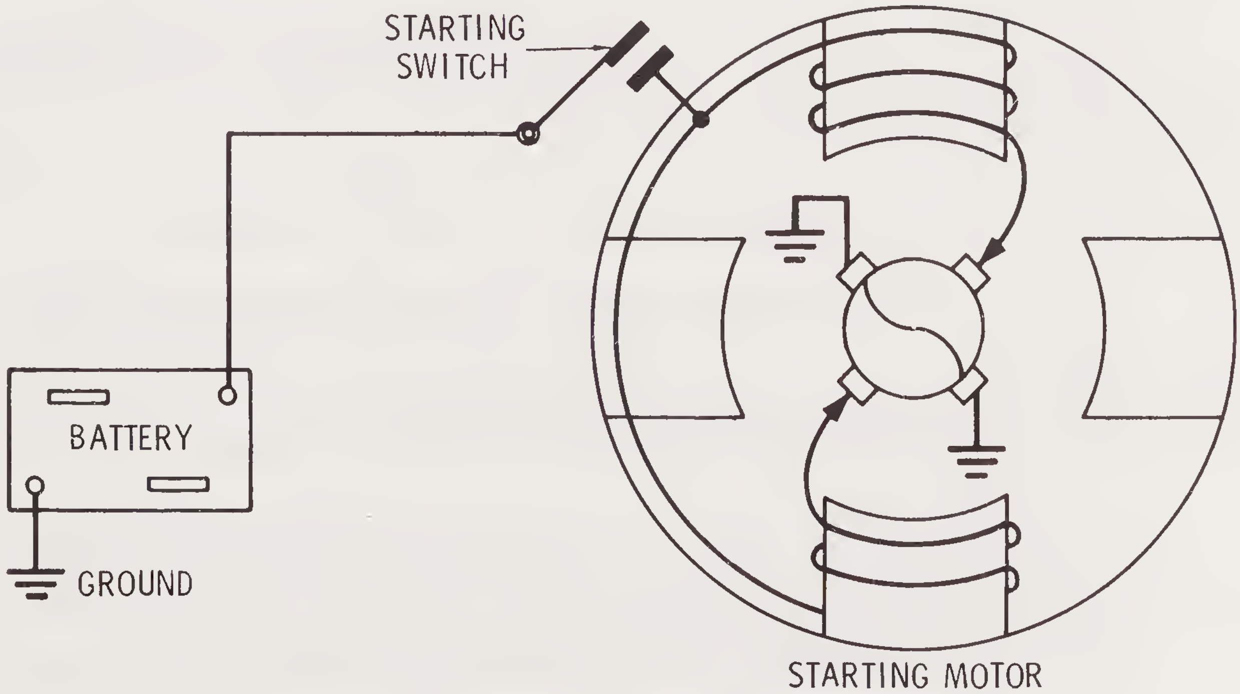



**Fig. 28-15. Typical starting-motor circuit.**

An open armature will show excessive arcing at the commutator bar, which is open, on the no-load test.

Tight or dirty bearings will reduce armature speed or prevent the armature turning. A worn bearing, bent shaft or loose pole shoe will allow the armature to drag, causing slow speed or failure of the armature to rotate. Check for these conditions.

If the brushes, bearings, commutators, etc., appear in good condition, the battery and external circuit also in good condition, and the cranking motor still does not operate correctly, remove the cranking motor and submit it to the no-load and torque test.

**Interpretation of No-Load and Torque Test Results.** The following indications apply:

1. Rated torque, current draw and no-load speed indicate normal condition of cranking motor.
2. Low free speed and high current draw with low developed torque may result from:
   *a.* Tight, dirty or worn bearings, bent armature shaft or loose field pole screws, which would allow the armature to drag.
   *b.* Shorted armature. Check armature further on growler.
   *c.* A grounded armature or field. Check by raising the grounded brushes and insulating them from the commutator with cardboard, and then checking with a test lamp between the insulated terminal and the frame. If test lamp lights, raise other brushes from commutator and check fields and commutator separately to determine whether it is the fields or the armature that is grounded.
3. Failure to operate with high current draw:
   *a.* A direct ground in the switch, terminal or fields.
   *b.* Frozen shaft bearings, which prevent the armature from turning.
4. Failure to operate with no current draw:
   *a.* Open field circuit. Inspect internal connections and trace circuit with a lamp test.
   *b.* Open armature coils. Inspect the commutator for badly burned bars. Running free speed, an open armature will show excessive arcing at the commutator bar, which is open.

*c.* Broken or weakened brush springs, worn brushes, high mica on the commutator, or other causes which would prevent good contact between the brushes and commutator. Any of these conditions will cause burned commutator bars.

5. Low no-load speed, with low torque and low current draw indicates:
   *a.* An open field winding. Raise and insulate ungrounded brushes from commutator and check fields with test lamp.
   *b.* High internal resistance due to poor connections, defective leads, dirty commutator and causes listed under 4*c*.
6. High free speed with low developed torque and high current draw indicates shorted fields. There is no easy way to detect shorted fields, since the field resistance is already low. If shorted fields are suspected, replace the fields and check for improvement in performance.

## Testing Starting-Motor Parts

### Field Coil Test for Continuous Circuit.

Place the test prod leads on the field coil leads. If the test lamp lights, the field coils are all right. If the test lamp does not light, there is an open circuit in one or both of the field coils.

### Field Coil Test for Ground.

Place one test prod lead to frame and the other to the field coil lead. If the test lamp does not light, the field coils are O.K. If the test lamp lights, one or both field coils are grounded.

### Individual Field Coil Test for Ground.

Break the soldered connection between the two field coils and test each one separately, replacing the field coil found to be grounded.

### Field Coil Leads Inspection.

Inspect the field coil leads where they are soldered at the starting switch terminal to be sure that they are tight.

### Armature Test for Ground.

Place one test prod on the armature and the other on the commutator. If the test lamp lights, the armature is grounded and should be replaced. If the test lamp does not light, the armature is O.K.

### Armature Test for Short Circuit.

Place the armature on the growler, and with a saw blade over the armature core, rotate the armature and test. If the saw blade does not vibrate, the armature is O.K. If the saw blade vibrates, the armature is short circuited and should be replaced.

### Commutator.

Inspect the commutator for roughness. If it is rough, turn down on a lathe until it is thoroughly cleaned, then sand off the commutator with 00 sandpaper.

### Insulated Brush Holder Test for Ground.

Place one test prod lead to the cover and the other on the brush holder. If the test lamp lights, the brush holder is grounded and should be replaced. If the test lamp does not light, the brush holder is O.K.

### Brushes.

Check condition of the brushes. If they are pitted or worn, they should be replaced.

Check the tension of the brush holder springs; they should have enough tension to hold the brushes snugly against the commutator.

### Brush Ground Leads.

Disconnect the brush ground leads from the end frame and clean all terminals and replace. Check the insulation of the brush to field coil leads. The insulation should not be broken.

### Drive Housing Bushing.

Check the condition of the drive housing bushing. The armature shaft should fit snugly in this bushing. If it is worn, it should be replaced.

To facilitate the service diagnosis, the following basic trouble pointers together with their possible causes and remedies are given:

# STARTING MOTOR DIAGNOSIS

## Conditions—Possible Causes—Remedies

**Starter fails to operate**

Possible Causes:

*a.* Corrosion at battery posts.
*b.* Loose battery cables.
*c.* Dead battery cell.
*d.* Defective starter or solenoid switch.
*e.* Defective starter.
*f.* Weak battery.

Remedies:

*a.* Remove battery cable and clean terminals and clamps. Check clamps for erosion and replace if necessary.
*b.* Clean battery posts and cable clamps. Tighten securely for good contact.
*c.* Replace defective battery. Check voltage regulator and generator output.
*d.* Replace starter and ignition switch and check starting-motor solenoid for operation. Replace if necessary.
*e.* Remove and test starting motor. Replace parts as required or the complete unit.
*f.* Test specific gravity of battery and check for dead cell.

**Starter fails and lights dim**

Possible Causes:

*a.* Weak battery.
*b.* Loose connections.
*c.* Dead battery cell.
*d.* Battery terminals corroded.
*e.* Internal ground in windings.

Remedies:

*a.* Test specific gravity of battery and check for dead cell.

*b.* Tighten loose connections as required, being sure to check terminals for corrosion.

*c.* Replace defective battery. Check voltage regulator and generator output, which may have contributed to the battery failure.

*d.* Remove battery cables and clean terminals and clamps. Check clamps for erosion and replace if necessary.

*e.* Remove starting motor and test.

**Starter turns but does not engage**

Possible Causes:

*a.* Broken drive spring.

*b.* Broken teeth on flywheel ring gear.

*c.* Grease or dirt on screw shaft.

*d.* Malfunctioning starter drive.

Remedies:

*a.* Remove starting motor and install new drive spring. Check screw shaft for excessive wear or burring. Replace if necessary.

*b.* Replace flywheel ring gear; be sure and check the teeth on mating pinion for wear and replace if necessary.

*c.* Remove starting motor and clean screw shaft in clean kerosene.

*d.* Replace drive assembly.

# CHAPTER 29

# Emission Controls Service

Of course, before any emission control is tested, a visual check of all connecting hoses and wires should be made.

There are many different types of emission controls being used, with testing procedures and specifications varying between manufacturers. To test or service any of the remaining systems, a factory service manual should be consulted. Only the systems most likely to produce operational problems and those serviceable by the user have been included.

## COMMON EMISSION CONTROLS

### Electric-Assist Choke

Each unit is specifically calibrated for its application and must be checked against the manufacturer's specifications for performance.

If either the choke unit or the heater control switch is malfunctioning, the faulty unit must be replaced.

## Choke Hot-Air Modulator

With the air cleaner removed, tape a thermometer near the modulator. If the modulator does not open or close within specified temperatures, remove and replace the unit. Also check condition of tubing (or hose) which connects the modulator to the heater coil, and replace it if it is damaged. Clean the interior of the hose if dirty.

## Crankcase Ventilation (PCV) System

If the engine operates erratically, remove the PCV valve. A dirty or stuck valve must be replaced. Also, at this time, check the condition of all the connecting hoses or tubing. All hoses and tubing must be in good (undamaged) condition and have airtight connections.

## Air-Pump Systems

System components can be checked separately, as follows:

### Air Pump.

Remove the outlet hose from the pump and, with the engine running, check to see if air is coming from the outlet where hose was removed. Air volume should increase as engine speed is increased. Reinstall hose and check to see if any air is leaking from the pump relief valve (if so equipped). The relief valve can be replaced (as a unit) if defective. If pump is excessively noisy or is seized, or if any of the above checks prove unsatisfactory, remove and replace the pump.

Check for proper drive-belt tension and pump mounting, and be sure all connecting hoses or tubes and the air manifold (on the engine) are free from air leakage. Also be sure carburetor air cleaner is properly installed.

### Air Bypass Valve.

First, determine whether the valve is receiving a vacuum signal by removing the hose from the signal port on the valve. With the engine running, place a finger over the end of the hose to feel whether a vacuum is present. If there is none, replace hose.

With valve signal hose reinstalled and with engine warmed up and idling, no air should be flowing out of valve outlet. Now, quickly open and close the engine throttle. This should cause a short blast of air to be expelled from the valve outlet. If the valve does not operate as described, it is defective and must be replaced.

### Check Valve.

Disconnect the hose from the check valve, but do not remove the valve from the air manifold. With the engine cool and not running, check for airflow into the manifold only. This can be done orally. If air can be sucked out of the air manifold, the check valve is defective and must be replaced.

### Mixture-Control or Backfire Valve

All hoses to the valve should be carefully checked, as any defective hose will cause the valve to malfunction. Replace defective hoses.

With all hoses connected and engine running at idle, disconnect the vacuum hose from the valve and place a finger over the end of the hose to feel whether a vacuum is present. If there is no vacuum, replace the vacuum hose.

Again, with all hoses connected and the engine running at idle, check the condition of the valve by first removing the hose which leads from the pump to the valve (disconnect hose at pump). If an air noise is heard at the hose, this indicates a leaking valve. Continue by placing a hand over the end of the hose. If a strong vacuum is felt or no air noise is now heard, this also indicates a defective valve. A leaking or defective valve must be replaced.

Another check will determine valve condition. Open and close the engine throttle quickly. The result should be a distinct but slowly decreasing air noise. Either a total lack of noise or an exceptional amount of noise also indicates a defective valve, which must be replaced.

### Pulse Air Injection Reactor (PAIR)

During engine idle, all the check valves and the air shutoff valve should be taking in air. Check all hoses and valves (starting with the air cleaner hose) for this condition. If any hose or valve does not function in this way, replace the faulty component.

### Thermostatic-Controlled Air Cleaner

Any defective components of this system must be removed and replaced. Particular attention should be paid if the *ambient temperature switch* does not operate at specified temperatures.

## FUEL-EVAPORATION EMISSION CONTROLS

CAUTIONS:

1. Since this is a system that contains gasoline vapors, be extremely careful not to use a torch or any other type of open flame near any of its components. A fire could occur and could lead to an explosion.
2. If a new gas tank cap is needed, be sure to replace it with the proper kind. If a vented cap is mistakenly used, it will render the system inoperative. If a cap without a double check valve is installed (again, mistakenly), engine fuel pump suction of the fuel from the storage tank will collapse the tank.

Check all system hoses to see that they have not been pinched shut or broken. If any lines need replacement, be sure they are marked "EVAP." Standard fuel hoses *cannot* be used on these systems, as they may clog or deteriorate.

Be sure the *charcoal canister* is replaced at specified intervals.

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